Reaction Time of Young Intellectual Deviates

BY

WINIFRED STARBUCK SCOTT, Ph.D.

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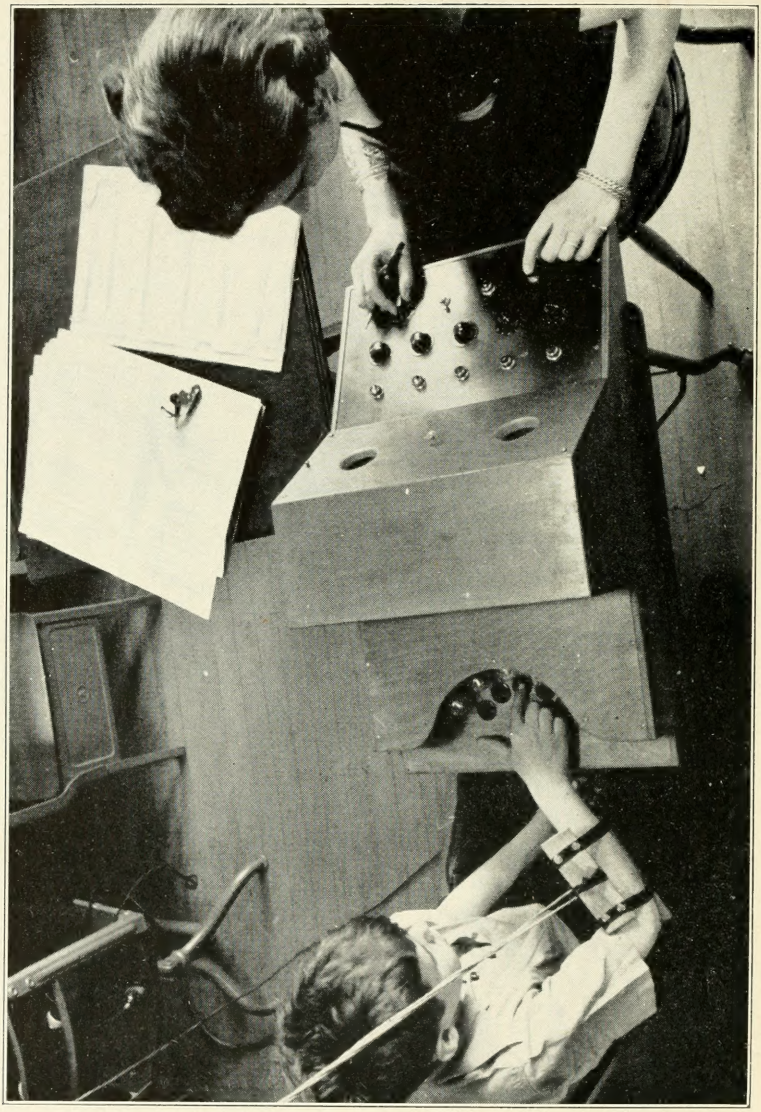

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The comparison of the reaction time of bright and dull children was undertaken at the suggestion of Professor Leta Stetter Hollingworth, under whose sponsorship the study was carried out.

It is with an added feeling of the deep personal loss of a friend that I share with her colleagues and students the realization of the tragic loss, through Mrs. Hollingworth's death, of a sympathetic teacher and a research worker of the highest integrity.

ACKNOWLEDGMENTS

The author is grateful to Professor Helen M. Walker for assistance in the choice of the statistical techniques used in analyzing the data; to Professor Irving Lorge for help in construction of the apparatus and for facilitating the testing program by providing for the transportation of some of the reagents; and to both Professor Walker and Professor Lorge for careful reading and criticism of the entire manuscript.

The author wishes to thank Professor Harry L. Hollingworth for helpful discussion of the techniques and problems of the study; Professor Robert Thorndike and Professor George Hartmann for advice on apparatus and on experimental procedure; Mr. George Dzwons for construction of the apparatus; Mr. Harry Kelley for help in transporting some of the children; Miss Dale Carter for help in finding children to pair with certain members of the H group; Miss Alice Kasper, principal of P. S. 500, Dr. Joseph I. Davidman, principal, and Mrs. Katherine Alfke, assistant principal of P. S. 43, and Dr. Lionel J. Simmonds, Executive Director, and Miss Donna Lithauer, psychologist, of the Hebrew Orphan Asylum, for permission to test the children; and to Dean Frank E. Henzlik, Professor Knute O. Broady and Professor Dean Worcester, of the University of Nebraska, for room and equipment used in computing results.

Professor Leta S. Hollingworth obtained the funds for construction of the apparatus, made available the testroom and the reagents used in the experiment and arranged assistance in many ways.

Without the understanding cooperation of my husband, Cecil Winfield Scott, the study could not have been undertaken.

CONTENTS

TABLES AND DIAGRAMS

CHAPTER I

INTRODUCTION

Reaction time is one of the phenomena of human behavior to which experimental psychologists earliest turned their attention,[1] and, as might be expected, one of the most frequently investigated aspects of the study of reaction time has been its relation to other types of behavior. Because the speed with which an individual can respond in a prescribed manner to a stimulus has been assumed indicative of a general speed ability, or considered a clue to the dynamics of the neuro-muscular mechanism[2] or even to the functioning of the nervous system itself, the relationship has often been sought between rates of speed in different tasks or skills,[3] between speed and ability in the same task,[4] and between speed in some task and ability in others.[5] In the last category are the numerous studies in which reaction time is correlated with estimates of "brightness"[6] or with intelligence defined as ability to respond satisfactorily to the variety of tasks included in a standardized scale.[7]

In spite of the tremendous literature on the subject, there is still disagreement among investigators as to whether a relationship exists between reaction time and intelligence. The confusion concerning

[1] The measurement of reaction time antedates the application of experimental methods in psychology: in 1850 Helmholtz published results of the first reaction-time experiments as such. Donders and de Jaeger (1865–1868) first emphasized the psychological rather than the physiological implications of the reaction method; in Wundt's "Grundzüge der physiologischen Psychologie" (1874), reaction-time measurements occupy a prominent place. See Henmon (20).

[2] Robinson (45): "The fact still remains that, by means of the several degrees of complexity represented by the reaction experiments, we can sample the operations of several levels of neuromuscular elaboration." (p. 631).

Goodenough (18): "The problem of reaction speed is one of considerable theoretical interest since the speed with which an individual is able to make a simple motor response to a perceived stimulus may fairly be regarded as a significant index to his basic level of perceptual-motor integration." (p. 431).

[3] Dowd (10), DuBois (11), Kennedy (30), Lanier (33), Seashore (49), Sisk (46), Walters (51).

[4] Freeman (14), Hunsicker (23), Kennedy (*cf.* 30), Kirkpatrick (31).

[5] Bernstein (5), Brown (6), Burt (7), Clark (8), Highsmith (22), Kelly (29), McCall (37), McFarland (38), Norsworthy (41), Peak and Boring (42), Walters (55).

[6] Gilbert (17).

[7] Beck (2), Farnsworth, Seashore and Tinker (13), Goodenough (18), Kennedy (30), Lanier (33), Lemmon (34), Peak and Boring (42), Philip (43), Sisk (50).

this question is well illustrated by conclusions of the more recent summarizers[8] of published experimental studies of speed and ability.

Hunsicker (23): "A survey of the literature on rate of work and mental ability is chiefly serviceable in that it discloses the far-reaching implications of the issue, and in that it reveales the amazing variability of the conclusions reached in equally well-sponsored experiments." (p. 1.) "The diversity in present views . . . ranges from positive denial of any relationship to insistence upon a high correlation between rate and ability." (p. 13.)

McFarland (38): "The more refined and objective the investigation the more convinced the experimenter [in the recent studies] becomes of a vital relationship between rate and mental ability as tested by the intelligence tests. The assertions concerning the amount and nature of that relationship, however, have become less dogmatic. It is evident, therefore, that further research confined to laboratory technique is necessary in order to clear the issue and to establish the negative or positive significance of this important psychological problem." (p. 610.)

Beck (2): "More recently Beck [3] reviewed the field, and he came to the conclusion that speed was only of minor, if any, importance in intelligence." (p. 793.)

Tinker (52): "Whenever valid measures of intelligence have been employed and when experimental conditions and size of group have been adequate, no appreciable relationship has been discovered between speed of simple reaction or speed of motor response and intelligence." (p. 451.)

(N. B.: McFarland's correlation of about +.60 between simple reaction and various measures of intelligence are "not accepted as significant until confirmed," because of the discrepancy between it and results obtained by Farnsworth, Seashore and Tinker (13).)

"A survey of the literature on the relation of speed of response to mental ability shows that no common factor runs through both motor (including reaction time) and mental test responses. However, there are group factors of varying degrees of specificity in motor responses and speed appears to be related to ability in mental and scholastic test responses when speed and ability are measured on the same kind of material." (p. 454.)

Lemmon (34): "Evidently, the question of the relation between reaction time and the higher abilities is not yet settled." (p. 9.)

It is, therefore, notable that whereas the question of the relationship between reaction time and "mental ability" is of great interest and has been the object of much investigation, there are no conclusive experimental data to confirm or deny the existence of such a relationship. On theoretical grounds the abilities to respond successfully when the specified overt response involves primarily speed of muscular action and when it involves primarily memory or problem-solving or the seeing of relationships are by some competent

[8] Historical sketches included in original reports of studies: Hunsicker (23), Jenkins (25), Lemmon (34), Sisk (50); special surveys of experimental data: Beck (3), Johnson (27), McFarland (38), Woodworth (60).

persons believed physiologically related[9] and by others held logically independent.[10]

In spite of the disparity in the general conclusions reached by investigators of the phenomena of reaction time, there has been built up from the numerous well-conducted experiments a tremendous body of data which can be accepted as sound within the limits of the particular studies. The following findings are relevant to the present investigation.

1. There are persistent individual differences in speed of reaction,[11] in relative speed to presentation or cessation of stimulus,[12] in relative speed after preparatory intervals of varying length,[13] and in variability of reaction.[14]
2. Correlations are fairly high for speed of response in simple discrete reaction of different types,[15] and for reaction times of different musculatures to the same stimulus.[16]
3. Correlations are low between simple reaction time and continuous motor activity, serial discrimination to auditory and to visual stimuli, accuracy in certain serial measures and a number of other diverse motor performances,[17] including moving the finger a short distance before pressing the response key.[18]
4. There seems to be a sex difference in favor of males.[19]
5. The changes in reaction time with chronological maturity are

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9 (a) For elaboration of one line of reasoning leading to such conclusions see Lemmon (34) p. 35. (b) Prof. L. S. Hollingworth found that superiority of an organism tends to be general, so that persons of superior intelligence tend to be superior also in muscular activity, and believed that reaction speed would be among those more purely physical activities in which persons of superior intelligence would excel those of inferior endowment. (c) Dr. R. M. Brickner believes that in its bare physical foundation, "the thinking process" is similar to other bodily processes such as walking or running, so that the comparison of somatic reaction time and "the thinking process" is a fruitful line of investigation.

10 For refutation of the line of reasoning of ref. 34, see Travis and Hunter (54) p. 391.

11 Gatewood (16), Goodenough (18), Kennedy (30), Henmon and Wells (20), Wells, Kelley and Murphy (56).

12 Woodrow (59).

13 Philip (43), Woodworth and Poffenberger (*cf.* 26).

14 Goodenough (18).

15 Beck (3), Lanier (33), Lemmon (34).

16 Reymert (*cf.* 49, pp. 42–43, and 60, p. 337).

17 Beck (3), Farnsworth, Seashore and Tinker (13), Lanier (33), Seashore (49).

18 Farmer and Chambers (12).

19 Bellis (4), Gilbert (17), Goodenough (18), Jones (28), Wissler (58); Philip (43) found boys faster than girls except in simple reaction to light with a warning signal.

increase in the speed[20] and especially in the stability of response[21] from childhood to adulthood, with decrease thereafter (from 60–89 years of age).[22]

6. When speed of reaction of college students, or of school children not selected on the basis of mental ability, is compared with scores on standardized intelligence tests, very low correlations are obtained.

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[20] Bathurst (1), Bellis (4), Gilbert (17), Goodenough (18), Jones (28), Philip (43).

[21] Goodenough (18), Luria (36).

[22] Miles (40), Ruger and Stoessiger (47).

CHAPTER II

THE PROBLEM AND ITS RELATION TO PREVIOUS INVESTIGATIONS

The experiment here reported was designed to determine whether children of high and those of low I.Q.[1] differ in speed of reaction to a visual stimulus, in variability of response, and in relative decrease of speed to increased complexity of the test situation. The hypothesis being tested was that there would be no difference between the groups in speed of simple reaction, but that a difference would appear and become progressively pronounced as the task was complicated by increase in either the number of units or the complexity of their arrangement.

Speed of response was measured by reaction-time apparatus devised specifically for this experiment in which the stimulus was a light or a light accompanied by sound,[2] and the response was the pressing of a telegraph key directly beneath the light and a short distance from the position in which the finger rested before appearance of the stimulus. Since in some parts of the test several response-keys were to be used, the mode of response had to involve either the use of more than one finger of one or both hands, or the traversing of a distance to the proper key. The latter method was adopted for it not only avoided the possible complication of dealing with the unequal ease of motion of the various fingers, but it also allowed a full arm movement which, especially for children, is believed simpler than a finger-wrist movement; and, by standardizing the mode of response for the entire test, it allowed the reagents' attention to be directed to the actual response.

The primary task, to react as quickly as possible on appearance

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[1] Throughout this report, I.Q. refers to the quotient computed from results of the Stanford Revision of the Binet-Simon Tests. The Stanford-Binet I.Q. was used as the basic criterion on which the two experimental groups were selected. Being a composite of a variety of tasks believed to involve or to be indicative of ability to learn, the Stanford-Binet test seemed to be for city school children a more adequate measure of mental ability, so defined, than would be any single task or different group of tasks such as might be evolved in accord with some opinion as to what better constitutes intellectual activity.

[2] When the Cenco Impulse Counters were in use, one for measuring the time of foreperiods and the other for measuring the response time (see p. 16), the cessation of the former and starting of the latter clock, though simultaneous, could be detected by a slight difference in tone of the two clocks. There was, therefore, an auditory stimulus signalling the appearance of the visual stimulus. Throughout the testing in which the Cenco timer was used only for its buzz, the sound was continuous from the beginning of the foreperiod until the correct response key was pressed.

of the stimulus, was complicated by varying the position of the light stimulus and correct response key, progressively increasing the number of potential positions from one to five, and by altering the light-key combinations. Variability of response was determined by the consistency with which the reagent maintained a rate throughout a series of trials on any light-key combination.

The present study, comparing reaction-time results of groups of children divergent on the basis of intelligence test scores, differs in several important aspects from previous studies of rate and ability.

1. Instead of attempting insofar as possible to rule out the individual's voluntary muscular response, as in the reflex studies,[3] or involving only a slight (and perhaps partially reflex[4]) movement of a small muscle group, as in the customary reaction-time studies in which a key is released (or depressed) by a finger already in contact with it, the procedure of the present experiment was such as to bring in a simple response of a large muscle group, and to require a voluntary movement toward a specified object. This procedure was designed to help avoid the measure, at one extreme, of responses which might be closer to a startle reaction than to a voluntary, organized movement, and, at the other extreme, of responses confused by attention directed toward the actual act of manipulation, as when more than one finger is used.[5]
2. The majority of studies in which conclusions are drawn concerning the relation between reaction time and intelligence have involved simple reaction time with but one stimulus and response; in the discriminative or choice reaction studies, the mode of response has required that a choice be made not only between stimuli, but also, in the response, between the two hands or between several fingers of one hand.[6] In the

[3] To test the hypothesis apparently inherent in the assumption of a relationship between reaction time and mental ability, that both are governed by the velocity of nerve impulses, reflex speed has been correlated with scores on ''mental'' (Rounds (46)) or ''intelligence'' (Travis and Young (54)) tests, with ''mental age'' (Whitehorn, Lundholm and Gardner (57)), and with simple reaction time (Lanier (33)).

[4] Cattell, Exner (*cf.* 60, pp. 305–306); James (24).

[5] In investigating the effects on reaction time of attention to the sensory stimulation as compared with attention to the muscular response, Cattell found that the reaction time of one of three reagents ''was lengthened by attention to the movement—just as, in ordinary life, the smooth, automatic act of going down stairs is disturbed by attention to one's legs.'' (*cf.* 60, p. 307.)

[6] Gatewood (16) concluded that ''there are measurable differences between the reactions of the several fingers,'' both in speed and in accuracy of response,

present study there was a choice of stimulus and of response key, but the same muscle group was used for any response.

Historically, a reaction involving a single stimulus and single response has been termed an a-reaction, or simple reaction; one involving more than one stimulus, with a different response to each, has been termed a b-reaction, or reaction with discrimination and choice; one involving response to one of two stimuli while requiring absence of response to the other has been termed a c-reaction, and was considered by Donders to involve discrimination only. Wundt, however, pointed out that the c-reaction is not purely a discriminative reaction but involves also choice of "movement" or "no movement."[7] Historically, then, in classifying similarly all reactions which involve multiple stimuli with a choice of responses many different types of reaction have been grouped together. Two experiments of Donders are illustrative. In one, for the a-reaction the reagent released a key with the finger of one hand; for the b-reaction he responded to one stimulus with the right hand and to the other with his left hand; for the c-reaction he responded to one stimulus with his right hand and made no response to the other stimulus. In the other experiment, for the a-reaction the reagent responded with a spoken "Ki" to the stimulus of a spoken "Ki"; for the b-reaction he responded with whichever one of five spoken syllables had been presented as a stimulus; and for the c-reaction he responded only to a particular one of the five syllables. Donders considered the middle part of both of these experiments a b-reaction; it seems to the present investigator, however, that in the first situation the b-reaction is less directly comparable to the a-reaction than in the second: not only must the reagent discriminate between the stimuli and choose between responses, but he must also choose between different muscle groups; and is it not probable that in so doing his response includes also a c-reaction since he must avoid a wrong response by the hand not called upon to react? Further, when but one muscle group is involved in the b-reaction, more complete readiness to react is possible

and in speed of response between the two hands; and that some subjects (those having piano practice or other similar practice) show less difference between the fingers than do others.

[7] An excellent discussion of the early attempts to measure the time of mental processes by finding the difference between the times of these types and of the d-type of reaction is given by Woodworth (60, pp. 302 ff.)

because direction of movement can be altered after the reactive movement has begun. The methods of the present study correspond to those of Donders' experiment using spoken syllables: in both experiments the same muscle group is involved in the a- and throughout the b-reaction, the response differing in the extent or direction of movement of those muscles.

3. Conclusions concerning the relationship between reaction time and "intelligence" have rested chiefly upon comparisons of college instructors or students, groups highly selected on the basis of the latter coordinate; since homogeneity of an experimental group tends to obscure relationships, in the present study the reagents were selected for their disparity on that coordinate.
4. Whereas most studies of reaction time have used adults as reagents, the reagents in the present study were children.[8] Adults available for testing, and representing divergent I.Q. groups, would probably also represent different occupational groups. Further, the relation between reaction time and mental ability might be a function of the particular part of the age span involved;[9] the adults used as reagents in many of the reaction-time experiments represent an age range during which probably some members of the group are at their maximum speed, some are still increasing in speed, while still others in the group have passed the age of their maximum speed;[10] in a group of children all reagents would still be increasing in speed. And it is possible that with children the reaction-time test has not the same significance that it has with adults.[11]

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[8] In previous studies in which reagents were children, their "brightness" was judged by their teacher without the aid of objective tests, or, where objective tests formed the basis of judgment, the group represented a range of ability which was unreported by the investigator.

[9] Lorge (35) says: "The problem of the relationship of speed of reaction to power in mental ability may be reopened on the field of the older adult. Speed of reaction is on the decline in adults after age thirty. Earlier in the life-span growth, decline and plateau may be the status of different individuals in a sample. The mixture of the three phases may obscure the true relationships of reaction speed to mental ability. It may be that a more thorough understanding of the nature of intelligence will be obtained by considering relationships among adults rather than among children or youths." However, it seems logical to assume that children within the particular age-range of those in the present experiment would all be in the same phase of growth.

[10] Bellis (4), Ruger and Stoessiger (47).

[11] Luriia (36), in reportng on his testing of children of about 2½ to 7 or 8 years of age, states: "The reaction to a signal, as we know it in the human adult, is a product of very complex development, an elaboration which arises on

5. Because of the findings of many investigators[12] that there is a most favorable interval between the signal and the presentation of the stimulus, and general agreement that this interval is for most people from 2″ to 2½″, work on the relation of reaction speed and mental ability in children has used, where reported, an interval varied within rather narrow limits around 2″. However, it has been found that the length of the optimum interval varies from one individual to another.[13] Since no work has been reported on the other attributes of persons whose fastest reactions are to any particular optimum length of interval, it is possible that those with the longest reaction times in a given test are those to whom the pre-presentation interval was least favorable. In the present experiment, therefore, the time elapsing between the signal and the presentation of the stimulus was varied throughout a wider range of interval length, and was controlled, each length used occurring the same number of times.
6. Many investigators have chosen to correlate speed and power by simultaneously measuring rate of work and quality of performance on the same material, assuming that the similarity of task for both measures tends best to isolate the two test factors. This type of investigation is valuable in determining quality at a given rate, or in determining rate of continuous work. Other investigators have attempted to determine the reagent's "customary" rate of motion.[14] The measure of rate of work, however, is a measure of time elapsed, and includes the timing of such factors as distraction, persistence, and fluctuation of attention, which are important

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the basis of other, considerably more primitive processes. The 'simple reaction' in young children differs from the reaction of adults in having another structure, and characterized by a marked specificity of the diffused excitation, a weakness of those higher regulating mechanisms which are undoubtedly a basic phenomenon in the neurodynamics of the adult. The development of the reactive processes from childhood to adult does not by any means take place by the quantitative improvement of the process but through a qualitative change in structure overcoming primordial diffusiveness and passing over into a new, controlling, intricate, functional, organized structure of the reaction. Those simple movements which we speak of as 'simple reactions' of the adult are, really, very late formations, built up on the basis of the suppressed, diffused system of the primitive impulses." (p. 338.)

[12] See Todd (53), pp. 11–12, for a review of early researches on the relation between interval and speed.

[13] Johnson (26) quotes Woodworth, R. S., and Poffenberger, A. T., "Experimental Psychology" (Mimeographed), 1920, p. 191, to this effect. Philip (43) says: "Just as one finds quite an individual variability in the length of the reaction, so one finds a large variability in the length of the optimum interval."

[14] Harrison and Dorcus (19).

> influences on the time an individual actually takes to perform. Just as the test of mental ability used in selecting reagents for the present study attempts to determine what an individual can do, and hence to minimize the influence of such factors, so it was desired that in this comparison of "power" and speed the speed test determine the individual's ability to respond quickly rather than either his customary rate of motion or his ability to maintain a speed.

Evidence of relationship between reaction speed and mental ability would probably be of practical value, even though the relationship were so small as to show only in groups divergent enough in mental ability to make a standardized intelligence test of little use in distinguishing them. Chiefly because of its theoretical significance, however, it is considered important to determine the presence or absence of a relationship between the facility of the thinking process and the facility of whatever process is represented by the response in a reaction-time test. The study here reported was designed to permit a relationship between I.Q. and speed of reaction, if present, to show.

CHAPTER III

THE EXPERIMENT

Description of Reagents

All reagents were public school children in the Borough of Manhattan, New York. Those constituting Group H were all of the children in the two classes for the gifted at P.S. 500, the Speyer School; those constituting Group L were chosen by pairing each child in Group H with a child of the same sex and chronological age but whose I.Q. derived from the Stanford-Binet test was less than 94.[1] All children in P.S. 500 who fitted the requirements for Group L of C.A., sex and I.Q. were included; to fill as many as possible of the remaining places children were brought in from the Hebrew Orphan Asylum and then, to fill the still remaining places, from P.S. 165. In no case was there a choice of two children to pair with any child in Group H, so that the stated factors were the only ones on which selection was made. Table I describes the experimental groups. There was in no case a discrepancy of more than two months between the children of a pair. There were two Negro girls and one Negro boy in both Group H and Group L; Japanese-American twins, a boy and a girl, in Group H could not be matched for race.

Data based upon matched pairs sometimes cannot correctly be generalized to a population of unmatched individuals, since the individuals sought for pairing can be found in only a specific portion of their population and so are not a true representation of it. If, for example, the reagents in the present study had been college students, the individuals in the L groups would undoubtedly not be typical of college age people of I.Q. below 94; or, had the young reagents of compulsory school attendance age been selected from opportunity classes they would probably not adequately represent school children of their particular I.Q. range. The classes for the gifted at the Speyer School were made up of children chosen with the specific intent of making the groups representative of gifted school children in the City of New York; and the members of the L groups in the present study were all enrolled in regular New York public school classes. Therefore, whereas technically any data

[1] The intent was to include in Group L only children with I.Q. between 70 and 90; in a few cases no such child could be found, and children of requisite age and sex were included whose I.Q. was as near as possible to the desired range.

TABLE I

DESCRIPTION OF REAGENTS

Data concerning the number, sex, I.Q. and chronological age of children in the experimental groups

Group	*N*	*Sex*	*Stanford-Binet I.Q.*		*C.A. on Date of Third Session*		*Mean Age of Children Used in Paired Computations*
			Range	*Median*	*Range*	*Mean*	
HB	26	Boys	120 to 194	142	9– 3 to 12– 1	10.19 yrs.	10.20 yrs.
LB	25	Boys	75 to 94	83	9– 1 to 12– 1	10.61 "	10.61 "
HG	25	Girls	120 to 200	138	8–11 to 11–10	10.42 "	10.36 "
LG	24	Girls	63 to 90	84	8–11 to 11–11	10.33 "	10.33 "

One girl and one boy from Group H could not be used in calculations based on pairs because no children of requisite age, I.Q. and sex were found to pair with them.

based upon these reagents can be generalized only to a population of matched pairs, it is believed that the findings would not be appreciably different from results characteristic of the total populations from which the pairs were drawn.

Apparatus

The apparatus[2] constructed for this experiment is shown in the accompanying picture and diagram. All electrical equipment was enclosed in a case so that the only parts visible were the five light bulbs and six smooth black buttons on the reagent's side, and, on the experimenter's side, the two clock faces and the several small lights and switches. The plug-in cord through which power was supplied was the only wiring which could be seen.

The reagent's side of the box had a small, slightly concave button on which the child's finger was placed at the "ready" signal and until the appearance of the stimulus; five 220-volt one-watt Neon bulbs arranged in an arc, close enough to one another[3] to permit binocular stimulation without change of focus;[4] directly beneath each bulb the manipulating button of the telegraph key by which the light was extinguished. The telegraph keys were submerged so that the only parts visible were the smooth black buttons which were flush with the platform and arranged in an arc whose radius was the distance to the center of the finger-rest: from the center of any response key button to the center of the finger-rest was 2 11/16 inches. Each button was one inch in diameter, and separated from the next one by 5/16 inch; the buttons were placed as close together as could be done while still keeping them clearly separated, in order that the movement from the finger-rest to the end response-buttons might have as little side motion as possible. The tension of the

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[2] The experimenter is indebted to Professor Irving Lorge for the general plan of having the reagent use the same finger for the response to any of the five reaction keys, as well as for the arrangement whereby any stimulus light could be connected with any response key. Professor Lorge also specified and ordered the parts to be used and Mr. George Dzwons designed the circuit and housing, to meet conditions of foreperiod timing, elimination of premature reactions, signalling of incorrect keys touched, relation of lights and keys to each other and to the finger-rest, and tension of keys, specified by the experimenter. The keys were designed by Professor Louis William Max of New York University. The second set of clocks was lent to the experimenter by Professor Lorge, and it was through him that the special keys designed by Professor Max were made available. Funds for parts and labor used in constructing the apparatus were made available by a grant from the Advanced School of Education, Teachers College, Columbia University.

[3] From the center of each bulb to the center of the next was $2\frac{5}{8}$ inches.

[4] Poffenberger (44) found an increase in reaction time with increase in separation of the stimulated area from the fovea, and faster reactions to binocular than to monocular stimulation.

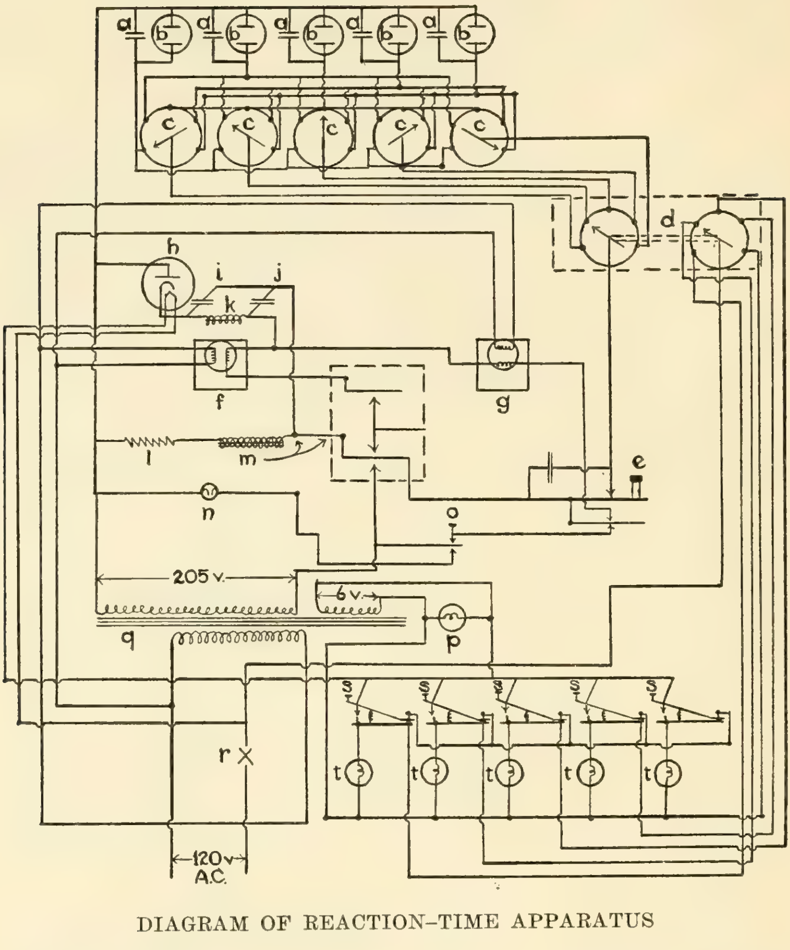

DIAGRAM OF REACTION–TIME APPARATUS

a. .003 uf. condensers
b. 1-watt Neon bulbs
c. light selector
d. key selector
e. operator's key
f. foreperiod timer
g. reaction timer
h. 84 rectifier tube
i. 1.5 uf. condenser
j. 10 uf. condenser
k. 15 henry 400 ohm choke
l. 1500 ohm 10-watt resistor
m. D. P. D. T. relay
n. finger-rest pilot light
o. finger-rest
p. on-off pilot light
q. power transformer
r. on-off switch
s. reaction keys
t. error lights

response keys was so adjusted that a 3-gram weight dropped from a height of 5/16 inch was sufficient to break the circuit, simultaneously stopping the response-timing clock and extinguishing the stimulus light.

On the experimenter's side of the apparatus were a small bulb which signalled whether the reagent's finger was on the rest-button; five small lights which indicated any response-button incorrectly touched; two clocks, on one of which was recorded the time elapsing between the starting of the preparatory buzz and the presentation of the stimulus, and on the other of which was recorded the time elapsing between the presentation of the stimulus and the correct response by the reagent; a triple-contact control key, the pressing of which started the buzzing foreperiod-timing clock, and release of which simultaneously stopped that clock, presented the stimulus, and started the second clock by which time for response was measured; five selector switches by which any light could be connected with any button; and an on-off switch supplying or cutting off current through the apparatus.

A pressure of 21 grams on the finger-rest maintained contact, illuminating the light which served as a subsidiary signal to the experimenter that the finger-rest was being pressed, and making possible presentation of the stimulus. Release of the finger-rest broke the circuit, stopping the foreperiod-timing clock and preventing the stimulus-light from appearing; since the clocks made an easily audible buzz while running, the reagent could tell by cessation of the sound that he was pressing too lightly (if at all). It was found desirable to have some signal such as the buzz which occurred throughout the preparatory period and until the correct response was made, to indicate during the preparatory period that the light would come on at any time, and thus keep the reagent aware that he should continue to watch the bulbs:[5] especially during the longer intervals it was found that otherwise the children would glance up to see whether the machine was working and the experimenter attending to business. Construction of the apparatus so that the circuit was broken by release of the finger-rest before presentation of the stimulus had as its purpose the prevention of premature responses, but there were further advantages which had not been predicted: it obviated the necessity of constant reiteration of in-

[5] The adults acting as reagents for experiments reported by Jenkins (25) believed that they were reacting faster to the removal than to the onset of the stimulus light, "complaining that they had difficulty in attending when no light was present." (p. 36.)

structions on the part of the experimenter, since the cessation or absence of sound served as a reminder to the reagent to press the rest-button; and the ability, which all children discovered during the practice trials through their over-eagerness to get to the response key, to stop the buzz and prevent the presentation of the stimulus seemed to give them a feeling of control over the situation and of active participation rather than mere waiting during the pre-presentation period.

Two sets of clocks were used during the months the experiment was in progress. The two clocks originally installed in the apparatus were the Central Scientific Company's high impedance impulse counters #73510, operating at 60 cycles a second, and recording in 1/120ths of a second.[6] Whether because of mechanical inability to vibrate at such high speed under continual use, or because, for ease of reading, the clocks were so mounted in the apparatus box that they were tilted, one clock or the other went out of control frequently enough to indicate the desirability of a change.[7] They were, therefore, replaced by the Standard Electric Time Company's clocks, Model S–1, DC Clutch, recording in 1/100ths of a second; the D.C. clutch was thrown by direct current rectified through an 84 tube off standard 60 cycle alternating current. The sound of these latter clocks in operation was slight. In order to reproduce as nearly as possible the conditions under which the experiment had been conducted up to the time of the change in clocks, one of the Cenco timers originally used was wired into the circuit so that it buzzed from the beginning of the foreperiod until the correct response was made. Part of the testing of the first two sessions, and all of the testing of the Third Session, a unit in itself, was timed by the second set of clocks.

An important auxiliary part of the apparatus was a large mirror placed back and slightly to one side of the reagent's chair, in which the experimenter could, with only slight eye movement from focus on the foreperiod-timing clock, watch the reagent's fingers before and during responses. This was found most useful, not only to discover such time-clipping techniques as that of keeping the finger-rest pressed with one finger while the others dangled just over the response keys, or the more ingenious device of extending the "finger-tip" to include the second joint of the finger, thereby appre-

[6] Scores were later converted to 1/100ths of a second.

[7] Schlosberg (44) pp. 57–58, reports similar experience with Cenco Impulse Counters.

ciably shortening the distance to be traversed to the response button; but also to be sure that each child was using the most advantageous technique of making a direct motion between finger-rest and response-button.

An adjustable arm-rest, suspended by a single cord from a horizontal pole, held the reagent's forearm at a uniform height slightly above the level of the response platform of the apparatus, and permitted an easy swing of the whole arm to move the finger from the rest to the response-button, thereby reducing variability of technique and number of muscles involved in the movement. An adjustable chair permitted raising or lowering the position of the child in relation to the arm-rest and apparatus.

Mode of Response

The reagent placed his forearm in the arm-rest, and, at the "ready" signal, the forefinger of his preferred hand on the finger-rest; on appearance of the stimulus, he touched the appropriate button with the same finger. It happened that every child preferred the right hand.

In setting up this experiment in which it was desired to use several lights and response keys the experimenter, as has been pointed out, chose to introduce the factor of the larger movement necessary in traversing a short distance to the response key, in order to avoid what was considered the greater disadvantage of dealing with the differential facility of the fingers; and since it was therefore necessary to traverse the distance in those series in which more than one light and button were used, it was, of course, deemed wise to use the same method for the series using but one light and button.

Premature Responses

The separation of the finger-rest and response keys made it possible, as has been explained in the description of the apparatus, to eliminate "false" or "premature" reactions mechanically, instead of having to identify them subjectively or eliminate them by a statistical device. The advisability of some such control over the reagent's finger-position before the stimulus appeared was discovered during preliminary testing with another machine, when it was found impossible, even by use of the mirror, for the experimenter to run the testing efficiently and also to determine accurately the trials in which the child was anticipating too overtly the onset of the stimulus.

Foreperiod

Since the desire was to measure the speed with which the children could respond after presentation of the stimulus, rather than to measure this plus time-interval judging ability, and because of the possibility that a preparatory interval favorable to one would be disadvantageous to another of the experimental groups, the interval between the start of the buzz following "ready" and the appearance of the stimulus was varied systematically throughout the testing, from one-half second to seven seconds in the first part of the experiment, and from one-half to five seconds in the Third Session. The order of the intervals was not random; but after an original determination by chance it was altered just enough to cause each interval length to precede any light the same number of times, and, insofar as possible, to be followed the same number of times by every length.

Procedure

The testing was conducted in a darkened room. Since there was daylight in the room, even though alterable in amount, only a rough approximation of light uniformity could be obtained; however, in view of the findings of Froeberg,[8] the relative stimulus-background brightness was considered sufficiently stable. Instructions and method of demonstrations throughout the testing were standardized. Insofar as possible, the members of a pair of children were tested successively, or at least on the same morning or afternoon.[9]

The testing of each child continued through three sessions at each of which the child was in the room from 16 to 30 minutes. At the beginning of the First Session, the apparatus was explained and demonstrated to each child, who then was allowed five[10] practice trials using correct technique; during the first trials, the method was corrected when the most efficient one was not adopted initially. Five practice trials, during which the middle light and key were used, preceded the testing at each of the three sessions. The demonstration of the lights to be used and the keys to be pressed in extinguishing them, and one practice trial for each light and key to be used for that series, preceded each of the tests.

[8] Froeberg (15), p. 33, says: "The greater the intensity of the stimulus, the shorter the reaction-time, until the intensity of the stimulus is great enough to be termed 'adequate,' after which 'even a change of 50% in the light intensity will make a difference of only a few sigma in the reaction time.' "

[9] Kleitman, Titelbaum and Feiveson (32) report diurnal variation in reaction time consistent for the five reagents used.

[10] In preliminary testing it had been determined that within five trials a child achieved at least his median speed of the 23-trial series which opened the testing period.

During the First Session the child completed a series of 23 successful trials on each of three tests; in the Second Session he completed a series of 23 successful trials on each of four tests, and ended with a repetition of half of the first series undertaken in the testing, the simplest one, using only the middle light and middle key. During the Third Session, besides a group of six trials at the beginning and at the end of the Session, each child completed a series of 24 successful trials on each of four tests on which he had previously been tested.

A *successful trial* was one in which the child was ready and cooperating: trials interrupted by coughing or sneezing, a loud street noise, glancing up, or other similar disturbance, although recorded, were considered invalid and were repeated at the end of the series. During the Third Session trials in which the key was missed were recorded, and substitute trials were given at the end of the particular group of trials; some of the group comparisons were based on the original as well as on the substitute trials.

The Tests

In all tests only one light appeared at a time and had only one key by which it was extinguished. In each test the reagent knew which lights were to be used, had seen which were the correct keys, and realized that he did not know the order in which the stimuli would be presented; he understood that in Tests I, II, III and IV, the correct key was the one directly beneath the stimulus light, and that in the other tests the correct key was never the one directly beneath the stimulus light.

Test I: *a*-reaction, using the middle light.

Test II: *b*-reaction, 2-choice: the second and fourth lights.

Test III: *b*-reaction, 3-choice: the middle and extreme lights.

Test IV: *b*-reaction, 5-choice: all five lights.

Test *xa*: A simple "learning" series in which the correct button was removed one place from the light, in a counterclockwise direction: light #1 was extinguished by key #2, light #2 by key #3, light #3 by key #4, light #4 by key #5, and light #5 by key #1.

Test *xb*: A complex learning series in which each light-button combination was probably more of a unit than a part of a pattern: light #1 was extinguished by key #3, light #2 by key #1, light #3 by key #5, light #4 by key #2, and light #5 by key #4.

Test *i*[11]: *c*-reaction: key #3 extinguished both lights #2 and #4; instructions were to react as quickly as possible to light #4, but not to react to #2. Test *i* was preceded by 10 trials using the middle key to extinguish either light #2 or light #4, each light being presented five times in irregular order; and was followed by six trials in which light #2 was extinguished by key #2 and light #4 by key #4.

In any test the order of presentation of the different lights was obtained by shuffling cards and then altering the resulting distribution where necessary to make each light follow and be followed by every light approximately the same number of times.

First and Second Sessions

For the first two sessions each pair of children was assigned to one of four groups having as nearly as possible the same average chronological age and the same number of boys and girls. Members of each of these groups received the tests in a different order; from treatment of results it was hoped to determine whether the order of presentation of the various tests appreciably affected performance on them.

Group		*Order of Presentation*						
A	Tests	I,	II,	*i;*	III,	IV,	*xa,*	*xb.*
B	"	I,	II,	*i;*	IV	*xb,*	III,	*xa.*
C	"	I,	IV,	*xb;*	*i,*	*xa,*	II,	III.
D	"	I,	*xb,*	*xa;*	IV,	III,	*i,*	II.

By the end of the Second Session, each child had completed, including trials at the beginning and end of the Second Session and those involved in Test *i*, a total of 193 successful trials.

Third Session

Procedure throughout the Third Session was the same for all individuals. Members of a pair were tested on the same morning or afternoon of the same day.

For this final session, it was desired not only to equalize as much as possible the influence of the order in which the tests were presented but also to have all children go through the same procedure, receiving the tests in the same order. Therefore, each test was divided into four parts of six trials each, and every child had six trials each of the following tests: I, II, III, IV; IV, III, II, I; (rest); IV,

[11] Results of Test *i* are not included in the present report.

III, II, I; (rest); I, II, III, IV. In order to reduce the effect of the initial and final positions of parts of any of the four tests, each child, before starting on the experimental series, did a group of six trials using the middle light; and he knew that after the tests he was to do another group of six trials using all five lights. Before starting on even the preliminary group each child was told the pattern of the complete test session, and both after the first four and after the first eight groups of trials it was made certain that he understood the pattern of what was to follow, including, of course, the final group of six trials.

On entering the testroom, each child was told that this was the time that really counted most: only his speediest score was wanted to-day, so that this time if he should miss the button or accidentally hit the wrong one, he should tell the experimenter who would not count that trial.

The Third Session was apparently the most successful of all; every child expressed preference of it over the previous sessions, and seemed thoroughly to enjoy it. Enthusiastic appraisal of performance at the end of the preliminary group, and praise at three other places throughout the Session, are believed to have contributed to the enjoyment. Much of the success of the Session, however, was probably inherent in the design: moving rapidly from test to test, possible because of the familiarity of each child with the situations, kept interest in all four series high throughout the 24 trials of each. And confidence in ability to control which trials should be counted may have improved performance.

CHAPTER IV

TREATMENT OF DATA AND RESULTS OF COMPUTATION

Individual Scores

The individual's score was a function of the time of his reactions in a test series, rounded to the nearest hundredth second. Except where otherwise specified, this function was the mean reaction time.

In order to have a score unaffected either by premature responses or by inattention, previous investigators of reaction-time phenomena have customarily used the median of trials as an individual's score. In the present experiment one end of the distribution of times of trials was restricted by prevention of premature responses; it seemed suitable to curtail the other end in some way, and the three slowest responses in each series were therefore discarded. The fastest 20 trials of the 23-trial series were chosen instead of 19 or 21 in order to simplify computation, and because there were breaks in the distributions of the individuals' times for any series between the main body of the distributions and the times of about three trials. It was considered wiser to set an arbitrary number of trials to discard than to attempt to judge each distribution separately; and because of the skewness of the distributions any criterion based on a measure of deviation, such as a three-standard-deviation yardstick, was unsatisfactory. As one object of the present experiment was to determine whether the members of any group differed from those of any other in their individual variability as well as in their speed of response, there was some special interest in basing comparisons both on scores indicating the quality of the majority or all of each individual's responses and also on those representing his best trials. In order to see whether reduction of each reagent's variability of response would significantly reduce the speed differences between the groups, certain basic comparisons were computed from scores of the fastest 10 instead of the fastest 20 trials.

In the Third Session both ends of the distribution of an individual's times were effected, one by the apparatus and the other by the discarding of trials in which the reagent reported he had not been ready or had missed the correct key. Although the children could decide not to count any particular trial, actually, as is evident in Table II, for any test the average number of trials discarded by any group for any reason was fewer than the three trials arbitrarily discarded by using only the fastest 20 of the 23 trials in the

First and Second Sessions. The girls averaged fewer discarded trials for the session than the boys, with the H girls discarding slightly fewer and the H boys somewhat more trials than the L groups, but differences were in all cases small and not consistent for the separate series; the L groups discarded somewhat more trials in Test I and somewhat fewer in Tests III and IV than did

TABLE II

Average Number of Trials Termed Invalid By Reagents During the Third Session

Test	*Boys*		*Girls*	
	H	*L*	*H*	*L*
I	0.81	1.32	0.84	1.21
II	2.39	2.36	1.56	2.17
III	2.42	1.76	1.96	1.79
IV	2.42	2.04	2.08	1.58
Total	8.04	7.48	6.44	6.75

the H groups. Computations of differences between pairs of reagents for the Third Session were based on mean as well as median scores both of original and of "good" trials for the purpose of determining whether trials replacing those the reagent considered invalid altered the resultant medians as much as the means, and whether by repeating trials either the H or L groups increased their relative speed appreciably more than did the other groups. In general, as is shown in Table VII (p. 37), the difference between the girls was decreased and the already highly significant difference between the boys was increased by the substitution of trials. Exceptions were the differences between pairs of girls in Tests II and IV: the differences in mean time were increased by the substitution of trials, indicating that in these two tests there was a greater difference between the times of discarded and of substitute trials of the H than of the L girls. Differences between results using original and those using substitute trials were not considered sufficient to merit repeating computations in order to use both; since the invalidity of the discarded trials was the assumption on which substitute reactions were obtained, further computations of Third Session results are based upon the 24 good trials.

Reliability of the Tests

The reliability of each test was computed by the Pearson product-moment method of correlation applied, (a) to the results of each

test given in different sessions; and (b) to the results of each test given during the Third Session. In determining reliabilities, all of the coefficients were computed from scatter diagrams in which the 100 cases were plotted, not from the same zero point, but as deviations, on the separate group (HB, LB, HG or LG) scatter diagrams, from the array or column containing the mean of that group. Because of the differences between the means of the various groups for any test, the correlation coefficients computed from scores treated as deviations from the separate group means are somewhat lower than those computed from scores treated as deviations from a fixed point.

The sum of the times of all 24 trials of each test of the Third Session was correlated with the sum of the times of the fastest 20 trials of that same test given in the First or Second Session. Results appear in Table III; subscript 3rd refers to the Third Session, and subscript 1st to the First or Second Session. For each test of the Third Session the sum of the times of the first and fourth of the four groups of six trials was correlated with the sum of the times of the second and third groups of trials. In Table III are given results of such computation as well as results after application of the Spearman-Brown prophecy formula; subscript 14 refers to the first and fourth groups of trials $(\sum_{1}^{6} X + \sum_{19}^{24} X)$, and subscript 23 to the two middle groups $(\sum_{7}^{12} X + \sum_{13}^{18} X)$.

TABLE III

RELIABILITY OF THE TESTS

N = 100

Correlation of each test of the Third Session with the fastest 20 trials of the same test in the First or Second Session†				*Correlation of half of each test of the Third Session with the other half of the same test*			
Test	$r_{1st \cdot 3rd}$	s_{1st}‡	s_{3rd}‡	$r_{14 \cdot 23}$	s_{14}‡	s_{23}‡	r (corrected)
I	.77	5.49	4.64	.86	4.93	4.34	.92
II	.71	9.64	5.18	.85	5.26	5.37	.92
III	.67	8.71	5.57	.87	6.11	5.56	.93
IV	.70	9.68	5.89	.89	5.86	6.19	.94

† No adjustment has been made for the different orders of presentation of the various tests in the First and Second Sessions.

‡ Standard deviations of total time have been reduced to standard deviations of mean scores.

Correlations between tests given in different sessions are appreciably lower than the self-correlation of tests given in the Third Session: it is known that results of reaction-time tests given to the same groups on different days are not identical; and it is reasonable to assume that the difference in procedure of the First or Second and of the Third Session influenced the correlations.

Group Differences in Reliability of the Tests

In order to determine whether the reliability of the tests differed for the H and L groups, coefficients of the reliability of Tests I to IV were computed for the two groups separately, and the significance of the difference between the reliability of each test for the two groups determined by applying the t-test, $t = \frac{z_1 - z_2}{s_{z_1 - z_2}}$, in which

$$z_1 = \tfrac{1}{2}\log_e\left(\frac{1 + r_1}{1 - r_1}\right) \text{ and } z_2 = \tfrac{1}{2}\log_e\left(\frac{1 + r_2}{1 - r_2}\right) \text{ and } s_{z_1 - z_2} = \sqrt{\frac{1}{N_1 - 3} + \frac{1}{N_2 - 3}}.$$

As for the combined groups, the self-correlations of the tests given during the Third Session were for both H and L groups higher than the correlations between tests given during different sessions. The H group was much less consistent than the L group in the mean time on test and re-test, except on Series I; for the tests given during the Third Session there was little difference between the reliability coefficients for the two groups except on Series III for which the reliability of the test was significantly greater for the L than for the H group.[1]

Correlations between Tests

Individual consistency in relative mean speed from series to series was determined by computing Pearson product-moment correlations between the individuals' times on different tests of the Third Session. Results[2] given in Table V show that in successive

[1] From these data alone it is not possible to tell whether the difference between the groups in reliability of the tests, as measured by correlations of times obtained during different sessions, indicates that fewer individuals in the L group showed practice effect or that more were able to maintain interest in the first test; a plausible explanation might be that there were more individuals in the H group who were unable to maintain high interest in the long series of repetitions of trials on each test during the First and Second Sessions, but who showed improvement in the Third Session because of keener interest maintained throughout each test. Nor is it possible to tell the cause of the greater reliability for the L group of Series III in the Third Session; members of the H group might be less able than those of the L to keep from attempting to predict the position of the next stimulus.

[2] As might be expected, these correlations are noticeably higher than those reported by other workers for simple and discriminative reaction tests. Lanier (33), for example, reports an average correlation of .44 between discrimination

TABLE IV

RELIABILITY OF THE TESTS FOR H AND L GROUPS

$N_H = 51$ $N_L = 49$

Test	*Correlation of each test of the Third Session with the fastest 20 trials of the same test in the First or Second Session*							*Correlation of half of each test of the Third Session with the other half of the same test*						
	H			*L*			*L–H*	*H*			*L*			*L–H*
	r	z	t_z	r	z	t_z	t_{z-z}	$r_{\frac{1}{2}\cdot\frac{1}{2}}$	z	t_z	$r_{\frac{1}{2}\cdot\frac{1}{2}}$	z	t_z	t_{z-z}
I	.68	0.83	5.75**	.82	1.16	7.85**	1.59	.90	1.47	10.20**	.84	1.22	8.28**	1.22
II	.51	0.56	3.90**	.75	0.97	6.60**	1.99*	.77	1.02	7.07**	.89	1.42	9.65**	1.95
III	.37	0.39	2.69**	.79	1.07	7.27**	3.31**	.75	0.97	6.74**	.90	1.47	9.99**	2.42*
IV	.45	0.48	3.36**	.78	1.05	7.09**	2.72**	.85	1.26	8.71**	.89	1.42	9.65**	0.80

Scores were treated as deviations from the means of the two sex groups. No adjustment was made for the different orders of presentation of the various tests in the First and Second Session.

series the ranking of the individuals changed but little and that even between the one-light and the five-light series individuals maintained to a rather high degree their positions in relation to the other reagents.

TABLE V

CORRELATIONS BETWEEN MEAN SCORES OF 100 REAGENTS ON DIFFERENT TESTS OF THE THIRD SESSION

Correlations†		*Standard Deviations*	
Test	*r*	*Test*	*s*
I · II	.91	I	4.57
II · III	.92	II	5.20
III · IV	.96	III	5.63
I · IV	.83	IV	5.98

† Each score was plotted as a deviation from its group mean.

MEAN TIME ON EACH TEST

For each group the mean of the individual mean times for each of the test series is given in Table VI.

The absolute time of response of the L boys for the a-reaction is seen to be rather similar to that of the H boys for the 2-light b-reaction test; the time of the L groups is greater on the 2-light test than is that of the respective H group on the 5-light test. For no group was there much difference in mean time on the 3- and on the 5-light tests.

During the First and Second Sessions, when all 23 trials of a series were given successively, the mean time on Test IV was for all groups except the H girls somewhat faster than the time on either Test II or III, and for the H girls it was faster than on Test III; during the Third Session, when each series was broken into four parts, the mean time increased from Test I to Test II to Test III, and was about the same for Tests III and IV. It is possible that during the long series there was an attempt to guess which light would go on next, in the 2- and 3-light tests, but a tendency to handle the 5-light test more in the manner of the 1-light, merely waiting for whatever stimulus appeared rather than trying to pre-

and simple reaction-time tests, and Lemmon (34) correlations ranging from .27 to .54. However, the discrimination test used by the former investigator was of the c-type, and the test of discrimination with choice involved both hands; that used by the latter involved discrimination between different numbers of lights, with response calling for choice between the two hands. It is to be remembered that in the present study the discrimination and choice were of position only, and all responses involved the same muscle group.

TABLE VI

MEAN OF MEAN REACTION TIME† FOR ALL SESSIONS

Trials	Test	Boys			Girls		
		H‡		*L*	*H*‡		*L*
		N = 26	*N = 25*	*N = 25*	*N = 25*	*N = 24*	*N = 24*
Fastest 20 trials in First and Second Sessions	I	36.32	36.31	42.76	40.46	40.62	44.19
	II	43.56	43.32	54.17	45.33	45.46	55.49
	III	44.56	44.41	56.07	49.08	49.07	55.71
	IV	41.77	41.66	53.86	46.77	46.76	53.74
	xa	67.49	67.33	98.09	72.98	73.26	102.79
	xb	141.10	140.11	185.47	152.62	154.22	212.51
24 "good" trials in Third Session	I	34.57	34.48	40.33	38.33	38.45	41.73
	II	39.96	39.89	46.51	43.12	43.27	48.14
	III	42.29	42.20	49.63	45.99	46.09	50.91
	IV	42.25	42.13	49.55	45.64	45.77	50.70
24 original trials in Third Session	I	35.59	35.51	41.45	37.67	39.19	42.79
	II	42.50	42.43	48.98	45.29	45.53	50.93
	III	44.42	44.32	52.18	47.96	48.11	52.86
	IV	44.58	44.51	51.87	47.84	48.06	52.15

† Times are given in hundredths of a second.

‡ For the H groups in each case are given the means for the total group as well as the means for those individuals used in paired computations.

dict which it would be; and that during the broken series there was less temptation to predict, since it was difficult to remember how many times any particular stimulus had already appeared.

DIFFERENCE IN SPEED BETWEEN THE PAIRS OF REAGENTS

Because of the relationship found by previous investigators between reaction time and both chronological age and sex, the reagents in the present experiment were paired on these bases, with one member of the pair a child of high and the other member a child of low I.Q. Differences between the pairs of reagents were determined, and their significance evaluated by application of "Student's" t-test for unique samples.[3]

For the 25 pairs of boys and the 24 pairs of girls differences between the scores of each pair were evaluated for each test of all sessions. For each group, the sum of the squared deviations from the mean difference ($\bar{x}$) between the pairs of reagents was divided by the number of degrees of freedom (24 for boys; 23 for girls), giving the mean square or variance, the square root of which yields the standard deviation (s). The standard error ($s_{\bar{x}}$) was derived by dividing the standard deviation by the square root of the num-

[3] The procedures followed are those described by Snedecor (51).

ber of differences. In judging the significance of the mean differences obtained the hypothesis that no difference existed between the groups, the scores of whose member pairs were being compared, was assumed and tested by the formula $t = \frac{\bar{x} - m}{s_{\bar{x}}}$ (in which $m = 0$, since "no difference" is assumed). As quoted from R. A. Fisher by Snedecor, the 5% and the 1% levels of t for 24 degrees of freedom are 2.064 and 2.797, respectively, and for 23 degrees of freedom are 2.069 and 2.807, respectively. According to these values, for the 25 pairs of boys a value of t as great as 2.797 would be expected to occur only once in 100 similarly obtained samplings of reaction times if there were really no difference in reaction speed between the group of boys for that test; a t-value of 2.064 would be expected to occur 5 times in 100 samples. For the boys, any value of t which exceeds 2.797 might be considered an indication that the null hypothesis may be rejected with a confidence of 99 percent, and that the results are representative of different grades of ability in reaction speed. Whether one is willing to reject the hypothesis of similarity of the experimental groups on odds of 99 to 1 against similarity, or to accept a conclusion of difference between the groups on odds of only 19 to 1 (fiducial probability, 95%) against similarity, is a matter of personal preference.[4] In tables of the present report in which values of t are given, values below the 5% level are unmarked, those between the 5% and 1% levels are followed by a single asterisk, and those in excess of the 1% level by a double asterisk.

Inspection of Table VII reveals that in all tests and sessions the H boys were definitely[5] faster than the L boys. This difference holds whether comparison is by median time or by mean of the fastest ten or the fastest twenty trials of the First and Second Sessions, or by mean or median time of either the original or the good trials of the Third Session. Although the H girls exceeded the L girls in speed in all tests of all sessions, differences between the girls is somewhat less marked in Test I, and in the median time of Test III of the Third and Test IV of the earlier sessions; had no trials been

[4] Davenport and Ekas (9), p. 38, term "significant" any t-value greater than that at the 5% level.

[5] In the present report, a difference between groups is termed definite when it is such that there is but one chance in 100 that the two experimental groups are drawn from populations not actually different on whatever is the basis of comparison. . The groups are considered moderately or somewhat different when the difference found indicates that there are between one and five chances in 100 that the experimental groups do not represent populations differing in the characteristic tested.

discarded in the Third Session, differences between the girls in mean time of Tests III and IV would have been less definite than they were after inclusion of substitute trials.

Results of the more complex test series are difficult to interpret correctly. It is believed that Test *xa* is directly comparable to the simpler series of the experiment, involving, in addition to what is required by the other tests, an ability to inhibit the response toward the stimulus light and redirect it quickly somewhat away from the light.[6] It is possible that, being a learning test, Test *xb* is not rightly included here as a reaction-time test: chance plays a part of indeterminate size; some reagents stress speed and some accuracy; some reagents who attempt to learn the combinations and also to react quickly become emotionally confused as they might not if they were trying to achieve either criterion alone. In comparisons of performance on the two tests speed and accuracy have been considered separately and also as interdependent factors. When the median of the 23 trials of the series is used as the individual's score for that test, comparisons for both Tests *xa* and *xb* show the H groups to be definitely faster than the respective L groups. In Test *xa,* the H and L groups made about the same number of errors; in Test *xb,* however, the L Girls made somewhat more errors than did the H Girls, and the L Boys made definitely more errors than did the H Boys. Since, in Test *xb,* the slower groups made more errors, both in number of trials in which wrong keys were pressed and in total number of wrong keys pressed, the possible explanation immediately becomes apparent that some or all of the extra time was used in pressing wrong keys. On the other hand, it is reasonable to assume that it may take at least as long to consider pressing certain keys, rule them out as wrong and decide on the correct key, as it takes to determine the rightness or wrongness of the keys by actually touching them. Viewed as wrong keys considered, errors could be made with or without manipulation. Any method is rather arbitrary by which to evaluate the performances of reagents who overtly make many mistakes quickly, of those who make few overt mistakes but take more time, and of those whose learning is indicated by the fact that they make fewer mistakes at the end than at the beginning of the series or that they make no

[6] In about 87% of the erroneous trials in Test *xa* the key first tried was either the one directly beneath the stimulus light or the one next to it but in a clockwise instead of counter-clockwise direction. Most of the errors of the L groups were of the latter type, whereas those of the H groups were predominantly to the key directly beneath the stimulus light.

TABLE VII

DIFFERENCE IN REACTION TIME† BETWEEN HIGH AND LOW I.Q. GROUPS

Comparisons of 25 pairs of boys and 24 pairs of girls similar in age, but differing in I.Q.

Test	*Boys (L–H)*						*Girls (L–H)*					
	Mean			*Median*			*Mean*			*Median*		
	$\bar{x}$	$s_{\bar{x}}$	t	$\bar{x}$	$s_{\bar{x}}$	t	$\bar{x}$	$s_{\bar{x}}$	t	$\bar{x}$	$s_{\bar{x}}$	t
I	6.46	1.53	4.23**	5.88	1.65	3.56**	3.56	1.27	2.80*	3.75	1.36	2.75*
II	10.85	3.00	3.62**	10.88	3.19	3.41**	10.03	2.24	4.48**	9.83	2.27	4.33**
III	11.66	2.69	4.33**	12.72	2.87	4.43**	6.64	1.50	4.44**	6.63	1.66	3.99**
IV	12.20	2.80	4.36**	12.52	2.80	4.47**	6.98	2.44	2.86**	7.25	2.61	2.78*
xa	30.76	8.59	3.58**	31.44	9.68	3.25**	29.53	6.19	4.77**	30.92	6.62	4.67**
xb	45.35	13.00	3.49**	51.28	10.65	4.81**	58.29	13.34	4.37**	68.25	17.52	3.89**
I	5.85	1.32	4.42**	5.84	1.40	4.18**	3.28	1.29	2.54*	3.17	1.34	2.36*
II	6.62	1.50	4.40**	6.24	1.76	3.56**	4.87	1.43	3.41**	4.88	1.43	3.41**
III	7.43	1.57	4.74**	7.32	1.77	4.13**	4.82	1.55	3.11**	4.54	1.64	2.77*
IV	7.42	1.77	4.20**	7.60	2.06	3.69**	4.93	1.51	3.25**	5.58	1.63	3.44**
I	5.94	1.49	4.00**	6.04	1.40	4.31**	3.60	1.33	2.71*	3.29	1.38	2.39*
II	6.54	1.88	3.49**	6.36	1.84	3.46**	5.40	1.51	3.56**	5.58	1.48	3.77**
III	7.87	2.10	3.75**	7.64	1.87	4.08**	4.75	1.78	2.67*	4.88	1.70	2.87**
IV	7.37	1.99	3.71**	7.64	2.10	3.63**	4.09	1.53	2.68*	5.75	1.67	3.45**

† Time is given in hundredths of a second.

mistakes on certain light-key combinations throughout the series. Comparison of the medians, as well as of the means, of only the correct trials of Test *xb* reduces the differences between H and L groups markedly. However, the use of only correct trials is of little value in this series: most of the scores are based on few, in some cases only one to four, trials; and it is impossible to determine for any reagent whether the few "correct" trials represent knowing accuracy or merely luck in trying the correct key first. The task set by Test *xb* was the same as that set by the other tests,—to get to the right key as quickly as possible; as in the other tests, the time of the trial was the time elapsing between the onset of the stimulus and the touching of the right key. So understood, the score on Test *xb,* as on the other series, should be the time taken to accomplish the task set. The H groups were definitely faster than the respective L groups in total time of the trials as well as on the median time of all trials of Test *xb.* In Test *xa,* when the individual's score is the total time of the trials, or either the median or the mean of just those trials in which no error was made,[7] results of comparisons are similar to those based on medians of the entire series: the H groups are definitely faster than the respective L groups.

Deceleration from Test to Test

Differences between the groups in decrease in speed from test to test were determined by subtracting each individual's time on one from the time on another test of the Third Session, and finding the t-value of the difference between pairs of reagents in the amount by which each member was slower on one test than on the other. Comparisons of decrease in speed to increase in number of lights used are probably more valid when based on results of the Third Session than on the First and Second Sessions since during the Third Session each individual reacted to Tests I, II, III and IV in one test session and the order of presentation of the tests made direct comparisons of them particularly suitable. Comparisons of decrease in median speed only are reported for Tests I, II, III and IV of the First and Second Sessions in order to provide as much continuity as possible in the comparisons for Tests *xa* and *xb* which were given during just the earlier sessions and for which median

[7] In using only the correct trials of Test *xa,* the scores are based on ten or more trials in all but four of the 100 cases; in all but nine cases the scores are derived from 15 or more correct trials.

TABLE VIII

TRIALS IN WHICH ERRORS OCCURRED

First and Second Sessions

Test	*Average number of trials in which errors occurred*				*Boys*			*Girls*		
	Boys		*Girls*							
	H	*L*	*H*	*L*	*d* (*L–H*)	$s_{\bar{d}}$	*t*	*d* (*L–H*)	$s_{\bar{d}}$	*t*
I	0.28	0.32	0.33	0.33	0.04	0.26	0.16	0.00	0.00	0.00
II	1.00	0.76	0.63	0.63	−0.24	1.90	−0.63	0.00	0.00	0.00
III	3.12	5.44	2.08	3.54	2.32	6.44	1.80	1.46	3.96	1.81
IV	12.28	15.60	12.88	15.46	3.32	4.25	3.91**	2.58	4.57	2.77*

time is considered the most adequate measure of the individual's time.

During the First and Second Sessions the L boys were slowed down more than were the H boys by the increase from one to two, three or five stimulus lights, but not appreciably so during the Third Session;[8] in all sessions the L girls were slowed down more than the H girls by the increase from one to two lights, but not appreciably more by further increase in the number of lights used. Both of the L groups were slowed down more by the complexity of Tests *xa* and *xb* than was either H group. In Table V it was seen that in successive series of the Third Session each individual maintained rather closely his speed rank within his group; in the present section it is seen that in general each group maintained rather closely not only its relative speed but also the absolute difference in time units by which it was faster or slower than the other groups.[9]

Variability of Response

In comparing the variability of response of the members of the experimental groups, the interest was not in the amount of dispersion within the group, but was, rather, in the consistency with which the individuals making up the group responded throughout a series of trials. This comparison[10] of the variability around their own means of the individuals of one group with those of another was based upon the individuals' standard deviations of responses

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[8] In order to try to determine whether during the Third Session the difference between the H and L boys in deceleration from test to test might constitute a significant trend even though the difference in deceleration between any two tests was not in itself significant, trend lines were computed showing the regression of mean reaction time upon the complexity of the test. The trend lines for the two groups were not significantly different from each other. However, since the use of regression coefficients assumes that the differences in difficulty between successive tests are equal, it is quite possible that such trend lines are not appropriate to these data. Another method of testing the conclusion of no difference between the groups in deceleration was tried: the mean difference between the H and L boys' mean deceleration from test to test $((6.18-5.41)+(3.12-2.31)+(-0.08--0.07)/3=0.52)$ was divided by its standard error; for two degrees of freedom, the result indicates that the difference is not significant.

[9] It is of interest that whereas the experimenter expected to find the experimental groups similar in the *a*-reaction but diverging in the *b*-reaction as the number of choices was increased, Professor Hollingworth predicted precisely the results found: significant dissimilarity between the H and L groups in the *a*-recation, with little further divergence in the *b*-reaction.

[10] The statistical procedure by which the groups were compared was devised by Professor Helen M. Walker. The subscript i indicates the individual standard deviation, or, used with a group subscript (k for any group, or 1 or 2 for two groups being compared) indicates the standard deviations of each individual in that group. Division by (24–1) would be consistent with the use of (N–1) in the denominator of s; however, since it would serve only to multiply each of the obtained values by a constant, it would have no effect on any tests of significance.

TABLE IX

DIFFERENCE IN DECREASE OF SPEED FROM TEST TO TEST

Comparisons of 25 pairs of boys and 24 pairs of girls similar in age but differing in I.Q.

Score	*Test*	*Boys*							*Girls*						
		H		*L*		$(\bar{d}_L-\bar{d}_H)$	$s_{\bar{d}}$	*t*	*H*		*L*		$(\bar{d}_L-\bar{d}_H)$	$s_{\bar{d}}$	*t*
		$\overline{Mdn}$	$\bar{d}$	$\overline{Mdn}$	$\bar{d}$				$\overline{Mdn}$	$\bar{d}$	$\overline{Mdn}$	$\bar{d}$			
Median of 23 trials in First and Second Sessions	I	37.16		43.04					41.38		45.13				
	(II–I)		7.08		12.08	5.00	2.31	2.16*		5.12		11.20	6.08	2.25	2.71*
	II	44.24		55.12					46.50		56.33				
	(III–I)		7.56		14.40	6.84	2.17	3.16**		8.79		11.66	2.87	1.84	1.56
	III	44.72		57.44					50.17		56.79				
	(IV–I)		4.92		11.56	6.64	2.00	3.31**		6.29		9.79	3.50	2.49	1.40
	IV	42.08		54.60					47.67		54.92				
	(IV–III)		–2.64		–2.84	–0.20	1.33	–0.15		–2.50		–1.87	0.63	1.93	0.32
	(xa–I)		32.80		58.36	25.56	8.68	2.95**		32.95		60.12	27.17	6.55	4.15**
	(xa–IV)		27.88		46.80	18.92	8.17	2.32*		26.66		50.33	23.67	6.47	3.66**
	xa	69.96		101.40					74.33		105.25				
	(xb–I)		106.68		152.08	45.40	10.09	4.50**		122.50		188.25	65.75	15.66	4.20**
	(xb–IV)		101.76		140.52	38.76	9.43	4.11**		116.21		178.46	62.25	16.08	3.87**
	xb	143.84		195.12					163.88		233.38				
		$\overline{M}$		$\overline{M}$					$\overline{M}$		$\overline{M}$				
Mean of 24 trials in Third Session	I	34.48		40.33					38.45		41.73				
	(II–I)		5.41		6.18	0.77	0.50	1.54		4.82		6.41	1.59	0.64	2.51*
	II	39.89		46.51					43.27		48.14				
	(III–I)		7.72		9.30	1.59	0.87	1.82		7.64		9.18	1.54	0.77	2.00
	III	42.20		49.63					46.09		50.91				
	(IV–I)		7.65		9.22	1.57	0.98	1.60		7.32		8.97	1.65	0.87	1.89
	IV	42.13		49.55					45.77		50.70				
	(III–II)		2.31		3.12	0.81	0.53	1.45		2.82		2.77	–0.05	0.49	–0.10
	(IV–III)		–0.07		–0.08	–0.01	0.48	–0.17		–0.32		–0.21	0.11	0.49	0.20

Time is given in hundredths of a second.

The time of the second-named test was subtracted from that of the first-named to give the time increases on which individuals were compared. The table may be read as follows: The H boys were on the average 7.08 hundredths seconds slower on Test II (on which the group mean of the median times was 44.24 hundredths seconds) that on Test I (37.16); the L boys averaged 12.08 hundredths seconds slower on Test II than on Test I (55.12–43.04 = 12.08). The difference between these mean differences (12.08–7.08 = 5.00) is the amount by which the deceleration of the L group from Test I to Test II was greater than that of the H group; this difference in deceleration divided by its standard error yields a t-value in excess of the 5% level of probability.

for each of the four tests of the Third Session. For each individual the standard deviation of the times of his 24 trials of a series was computed: $s_i = \sqrt{\dfrac{\sum_1^{24} X^2 - \dfrac{(\sum_1^{24} X)^2}{24}}{24}}$; and for each group the mean of these individual standard deviations, $\bar{s} = \dfrac{\sum_1^{N} s_i}{N}$, and their standard deviation, $s_{s_k} = \sqrt{\dfrac{\sum_1^{N_k} s_{ik}^2 - \dfrac{(\sum_1^{N_k} s_{ik})^2}{N_k}}{N_k - 1}}$ were determined. The estimate of the variance of the standard deviation for both groups being compared, $\sigma^2 s_{1+2} = \dfrac{\sum_1^{N_1} s_{i1}^2 - \dfrac{(\sum_1^{N_1} s_{i1})^2}{N_1} + \sum_1^{N_2} s_{i2}^2 - \dfrac{(\sum_1^{N_2} s_{i2})^2}{N_2}}{N_1 + N_2 - 2}$, was the basis for determination of the standard error of the difference between the mean standard deviations of the two groups: $\sigma_{\bar{s}_1 - \bar{s}_2} = \sqrt{\dfrac{\sigma^2 s_{1+2}(N_1+N_2)}{2(N_1)\ (N_2)}}$ The value by which the significance of the difference between the consistency of response of the individuals of two groups was judged was the ratio of the difference between the means of the standard deviations of the individuals of the two groups to the standard error of the difference between those mean standard deviations: $t = \dfrac{\sigma \bar{s}_1 - \bar{s}_2}{\bar{s}_1 - \bar{s}_2}$. Results of comparisons of variability around their own means of the members of the various experimental groups are summarized in Table X.

Members of the low I.Q. groups were significantly more variable in their responses to any of the tests given in the Third Session than were individuals in the respective high I.Q. groups.[11] Within either the low or the high I.Q. group, there was little difference between the boys and the girls except in Tests I and IV in which the high I.Q. girls were less consistent than the boys.

[11] Other investigators report that increase in chronological age is accompanied by decrease in both time and variability of reactions (pp. 9–10). The data presented in Tables VII and X indicate that in both speed and variability the reactions of the low I.Q. group were more characteristic of immaturity than were those of the high I.Q. group.

TABLE X

DIFFERENCE IN CONSISTENCY OF RESPONSE OF INDIVIDUALS COMPRISING EXPERIMENTAL GROUPS

Results of Third Session Testing

Test	Boys					Girls					High I.Q. Groups	Low I.Q. Groups
	$\bar{s}_H$	s_{s_H}	$\bar{s}_L$	s_{s_L}	t $\frac{\bar{s}_L - \bar{s}_H}{\sigma_{\bar{s}_L - \bar{s}_H}}$	$\bar{s}_H$	s_{s_H}	$\bar{s}_L$	s_{s_L}	t $\frac{\bar{s}_L - \bar{s}_H}{\sigma_{\bar{s}_L - \bar{s}_H}}$	t $\frac{\bar{s}_G - \bar{s}_B}{\sigma_{\bar{s}_G - \bar{s}_B}}$	t $\frac{\bar{s}_G - \bar{s}_B}{\sigma_{\bar{s}_G - \bar{s}_B}}$
I	3.06	0.89	4.24	1.67	4.46**	3.56	0.84	4.69	1.82	3.97**	2.94*	1.30
II	4.70	1.53	6.22	1.69	4.76**	5.07	1.10	6.26	1.86	3.87**	1.40	0.12
III	5.67	1.21	6.89	1.95	3.81**	6.04	1.43	7.00	1.74	3.02**	1.39	0.31
IV	5.42	1.29	7.00	2.43	4.12**	6.06	1.30	7.70	2.36	4.23**	2.51*	1.40

INFLUENCE OF AGE, SEX, I.Q., AND ORDER IN WHICH TESTS WERE PRESENTED[12]

The method of analysis of variance[13] was used to isolate the variation due to chronological age, to sex, to the division into groups on the basis of I.Q., and to the order of presentation of the various tests during the First and Second Sessions. Because of the narrow age range of the reagents in the present study, the experimental groups were divided into sub-groups according to age, and all children within any sub-group were considered to be of the same age. During the First and Second Sessions the sub-groups represented a range of eleven months, and during the Third Session a range of ten or eleven months, distributed as shown in Table XI.[14]

TABLE XI

CHRONOLOGICAL AGE GROUPS

C.A. Range	N†	Boys H Ave. C.A.	Boys H N	Boys L Ave. C.A.	Boys L N	Girls H Ave. C.A.	Girls H N	Girls L Ave. C.A.	Girls L N
First and Second Sessions									
11– 2 to 11–9	17	11– 7.3	4	11– 6.6	5	11– 3.8	4	11– 3.5	4
10– 4 to 11–2	33	10– 8.4	8	10– 9.0	8	10– 6.8	9	10– 6.4	8
9– 5 to 10–3	25	9–10.4	9	9–11.0	7	9–10.5	4	9– 9.2	5
8– 6 to 9–4	25	9– 1.6	5	9– 1.4	5	8–11.9	8	9– 0.4	7
Third Session									
11– 6 to 12–3	16	11–10.2	5	11–11.3	4	11– 7.8	4	11– 7.7	3
10– 8 to 11–5	34	10–11.3	8	11– 1.6	8	10–11.0	9	10–10.8	9
9–10 to 10–7	23	10– 1.5	8	10– 2.5	8	10– 2.8	4	10– 3.7	3
8–11 to 9–9	27	9– 5.4	5	9– 4.2	5	9– 4.0	8	9– 4.1	9

† See footnote 14.

An individual's score was the mean of his fastest 20 trials of the 23-trial series, or the median of the 24-trial series. In the case of each factor the sum of squares was derived from the totals of the

[12] It will be remembered that the experimental groups were originally divided into four groups to each of which the test series were presented in a different order; and that on the assumption of effect on reaction time of both sex and chronological age, these were the bases on which the reagents were paired.

[13] The analysis of variance evolved by R. A. Fisher is described and explained by Snedecor (51).

[14] In all cases the age was that on actual date of test; since the testing of the Third Session was conducted over a much shorter period than was that of the First and Second Sessions, and the order in which the children were tested was not exactly the same in both periods, there was some change in the constitution of the sub-groups.

scores of individuals in the appropriate I.Q. or sex group, or order-of-presentation or age classification:[15] in any classification the sum of the quotients obtained for each sub-group by dividing the square of the sub-group total by the number of scores making up that total was reduced by the amount of the correction term, the average for the entire group of the squared sum of scores of the entire group. The total sum of squares is the Ns^2 total, or the difference between the correction term and the sum for the group of the squared scores. The significance of any source of variation is concluded from the ratio between its mean square and that of the discrepance or experimental error: the quotient is compared with the tabular values of F for the corresponding degrees of freedom of the two factors. Comparison of the mean squares of a particular source of variation and the experimental error entered as discrepance or as variation within subclasses indicates the relative spread of scores within and between classifications; for example, in Table XII, the size of the mean squares indicates that for any test there was about as much spread among the mean times of those reagents who had the tests in a given order as there was between the times of individuals who took the tests in different order. In Tables XII through XV, those sources of variation which yield an F between the 5% and the 1% level are followed by an asterisk; the high significance of those which exceed the 1% level is indicated by a double asterisk.

In general, the order in which the various tests were presented had less influence than age group on the time of reaction; this was markedly true throughout for both of the L groups; for the H girls in Test IV and the H boys in Tests III and IV, the order in which the tests were given was more important than age group in influencing the reaction time, but in no case was the difference in time between the order groups significantly greater than the variability within the order groups.

The analyses show that within the chronological age range of the reagents, in speed on the simplest test there was not enough difference between the age groups to be termed significant when each sex or I.Q. group was considered separately, but there was enough to emerge as moderately important when the times of all 100 reagents were considered together. As might be expected, during the Third Session when all tests were given in one period and to all reagents in the same order, the influence of the age grouping was more pro-

[15] The disproportionate frequencies in the various classes render the computations only approximate, but the frequencies are so nearly proportionate that presumably no large error is introduced.

TABLE XII–A

ANALYSIS OF VARIANCE OF MEAN REACTION TIME OF 100 CHILDREN CLASSIFIED BY I.Q. GROUP AND SEX ACCORDING TO ORDER IN WHICH TESTS WERE PRESENTED

Tests I–IV of the First and Second Sessions

Tests	51 Children of High and 49 of Low I.Q.				51 Boys and 49 Girls			
	Source of Variation	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*	*Source of Variation*	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*
I	Total	99	3,771.61		Total	99	3,771.61	
	I.Q.	1	652.06	652.06**	Sex	1	197.50	197.50*
	Order	3	3.09	1.03	Order	3	3.09	1.03
	I.Q.-Order Interaction	3	110.48	36.83	Sex-Order Interaction	3	195.06	65.02
	Within Subclasses (error)	92	3,005.98	32.67	Within Subclasses	92	3,375.96	36.70
II	Total	99	12,447.52		Total	99	12,447.52	
	I.Q.	1	2,699.01	2,699.01**	Sex	1	59.64	59.64
	Order	3	461.25	153.75	Order	3	461.25	153.75
	I.Q.-Order Interaction	3	307.01	102.34	Sex-Order Interaction	3	332.87	110.96
	Within Subclasses	92	8,980.25	97.61	Within Subclasses	92	11,593.76	126.02
III	Total	99	9,884.04		Total	99	9,884.04	
	I.Q.	1	2,080.92	2,080.92**	Sex	1	112.64	112.64
	Order	3	300.55	100.18	Order	3	300.55	100.18
	I.Q.-Order Interaction	3	454.28	151.43	Sex-Order Interaction	3	122.84	40.95
	Within Subclasses	92	7,048.29	76.61	Within Subclasses	92	9,348.00	101.61
IV	Total	99	12,063.26		Total	99	12,063.26	
	I.Q.	1	2,293.59	2,293.59**	Sex	1	154.71	154.71
	Order	3	222.80	74.27	Order	3	222.80	74.27
	I.Q.-Order Interaction	3	403.39	134.46	Sex-Order Interaction	3	–1.00	–0.33
	Within Subclasses	92	9,143.48	99.39	Within Subclasses	92	11,686.75	127.03

TABLE XII–B

ANALYSIS OF VARIANCE OF MEAN REACTION TIME OF 100 CHILDREN CLASSIFIED BY I.Q. GROUP AND SEX ACCORDING TO AGE
Tests I–IV of the First and Second Sessions

Tests	51 Children of High and 49 of Low I.Q.				51 Boys and 49 Girls			
	Source of Variation	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*	*Source of Variation*	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*
I	Total	99	3,771.45		Total	99	3,771.45	
	I.Q.	1	651.90	651.90**	Sex	1	197.33	197.33*
	Age	3	429.21	143.07**	Age	3	429.20	143.07**
	I.Q.-Age Interaction	3	32.75	10.92	Sex-Age Interaction	3	– 34.97	– 11.66
	Within Subclasses	92	2,657.61	28.89	Within Subclasses	92	3,179.88	34.56
II	Total	99	12,447.42		Total	99	12,447.42	
	I.Q.	1	2,698.91	2,698.91**	Sex	1	59.54	59.54
	Age	3	2,063.19	687.73**	Age	3	2,063.19	687.73**
	I.Q.-Age Interaction	3	586.33	195.44	Sex-Age Interaction	3	110.53	36.84
	Within Subclasses	92	7,098.99	77.16	Within Subclasses	92	10,214.16	111.02
III	Total	99	9,883.83		Total	99	9,883.83	
	I.Q.	1	2,080.72	2,080.72**	Sex	1	112.43	112.43
	Age	3	1,735.43	578.48**	Age	3	1,735.43	578.48**
	I.Q.-Age Interaction	3	168.54	56.18	Sex-Age Interaction	3	14.91	4.97
	Within Subclasses	92	5,899.15	64.12	Within Subclasses	92	7,021.06	76.32
IV	Total	99	12,063.65		Total	99	12,063.65	
	I.Q.	1	1,254.62	1,254.62**	Sex	1	155.10	155.10
	Age	3	2,293.98	764.66**	Age	3	1,254.62	418.21*
	I.Q.-Age Interaction	3	486.33	162.11	Sex-Age Interaction	3	– 23.09	– 7.70
	Within Subclasses	92	8,028.72	87.27	Within Subclasses	92	10,677.02	116.05

TABLE XIII

ANALYSIS OF VARIANCE OF MEAN REACTION TIME OF 51 BOYS AND OF 49 GIRLS CLASSIFIED ACCORDING TO AGE AND I.Q. GROUP
Tests I–IV of the First and Second Sessions

Tests	*Source of Variation*	*Boys*			*Girls*		
		Degrees of Freedom	*Sum of Squares*	*Mean Square*	*Degrees of Freedom*	*Sum of Squares*	*Mean Square*
I	Total	50	2,250.89		48	1,323.22	
	I.Q. Group	1	528.97	528.97**	1	169.61	169.61*
	Age Group	3	218.64	72.88	3	175.59	58.53
	Age-I.Q. Interaction	3	111.80	37.27	3	19.02	6.34
	Within Subclasses (error)	43	1,391.48	32.36	41	959.00	23.39
II	Total	50	7,958.70		48	4,429.18	
	I.Q. Group	1	1,436.10	1,436.10**	1	1,264.50	1,264.50**
	Age Group	3	1,378.35	459.45**	3	795.36	265.12**
	Age-I.Q. Interaction	3	879.51	293.27*	3	−140.03	−46.68
	Within Subclasses	43	4,264.73	99.18	41	2,509.20	61.20
III	Total	50	6,831.94		48	2,939.46	
	I.Q. Group	1	1,690.82	1,690.82**	1	539.30	539.30**
	Age Group	3	993.13	331.04*	3	757.21	252.40**
	Age-I.Q. Interaction	3	485.88	161.96	3	41.12	13.71
	Within Subclasses	43	3,662.11	85.17	41	1,601.82	39.07
IV	Total	50	6,904.72		48	5,003.84	
	I.Q. Group	1	1,860.62	1,860.62**	1	596.19	596.19*
	Age Group	3	757.27	252.42*	3	474.26	158.09
	Age-I.Q. Interaction	3	656.22	218.74	3	86.60	28.87
	Within Subclasses	43	3,630.61	84.43	41	3,846.79	93.82

TABLE XIV

Analysis of Variance of Median Reaction Time of 51 Boys and of 49 Girls Classified According to Age and I.Q. Group

Results of Third Session Testing

Tests	Source of Variation	Boys: Degrees of Freedom	Boys: Sum of Squares	Boys: Mean Square	Girls: Degrees of Freedom	Girls: Sum of Squares	Girls: Mean Square
I	Total	50	1,662.71		48	871.51	
	I.Q. Group	1	426.28	426.28**	1	126.04	126.04**
	Age Group	3	187.17	62.39	3	51.28	17.09
	Age-I.Q. Interaction	3	72.18	24.06	3	11.11	3.70
	Within Subclasses (error)	43	977.08	22.72	41	683.07	16.66
II	Total	50	2,296.62		48	1,313.62	
	I.Q. Group	1	509.49	509.49**	1	319.64	319.64**
	Age Group	3	317.90	105.97*	3	137.06	45.69
	Age-I.Q. Interaction	3	188.03	62.68	3	–13.72	–4.57
	Within Subclasses	43	1,281.21	29.80	41	870.64	21.24
III	Total	50	2,482.73		48	1,568.28	
	I.Q. Group	1	688.50	688.50**	1	265.13	265.13**
	Age Group	3	392.36	130.79**	3	190.99	63.66
	Age-I.Q. Interaction	3	207.15	69.05	3	–1.85	–0.62
	Within Subclasses	43	1,194.72	27.78	41	1,114.01	27.17
IV	Total	50	2,365.03		48	1,787.90	
	I.Q. Group	1	625.44	625.44**	1	403.77	403.77**
	Age Group	3	168.54	56.18	3	311.77	103.92*
	Age-I.Q. Interaction	3	146.52	48.84	3	1.71	0.57
	Within Subclasses	43	1,424.53	33.13	41	1,070.65	26.11

TABLE XV

ANALYSIS OF VARIANCE OF MEDIAN REACTION TIME OF 100 CHILDREN CLASSIFIED BY I.Q. GROUP ACCORDING TO AGE GROUP AND SEX
Results of Third Session Testing

Tests	Source of Variation	High I.Q. Groups			Low I.Q. Groups			High I.Q. Girls and Low I.Q. Boys		
		Degrees of Freedom	Sum of Squares	Mean Square	Degrees of Freedom	Sum of Squares	Mean Square	Degrees of Freedom	Sum of Squares	Mean Square
I	Total	50	767.50		48	1,393.48		49	1,362.44	
	Sex	1	165.99	165.99**	1	13.09	13.09	1	59.10	59.10
	Age Group	3	66.91	22.30	3	132.31	44.10	3	169.12	56.37
	Age-Sex Interaction	3	16.62	5.54	3	105.91	35.30	3	118.11	39.70
	Within Subclasses (error)	43	517.98	12.04	41	1,142.17	27.86	42	1,016.11	24.19
II	Total	50	801.46		48	2,146.54		49	1,920.40	
	Sex	1	123.00	123.00**	1	43.89	43.89	1	129.28	129.28*
	Age Group	3	112.17	37.72*	3	365.21	121.74*	3	326.18	108.73*
	Age-Sex Interaction	3	4.27	1.42	3	147.62	49.21	3	255.40	85.13
	Within Subclasses	43	562.03	13.07	41	1,589.82	38.78	42	1,209.53	28.80
III	Total	50	1,114.72		48	2,194.22		49	1,899.27	
	Sex	1	193.84	193.84**	1	17.73	17.73	1	148.78	148.78*
	Age Group	3	153.31	51.10*	3	471.88	157.29*	3	379.05	126.35**
	Age-Sex Interaction	3	26.18	8.73	3	137.28	45.76	3	278.51	92.84
	Within Subclasses	43	741.40	17.24	41	1,567.34	38.23	42	1,092.93	26.02
IV	Total	50	1,133.50		48	2,175.30		49	1,855.43	
	Sex	1	135.95	135.95**	1	49.13	49.13	1	174.77	174.77*
	Age Groug	3	121.50	40.50	3	388.85	129.62*	3	317.58	105.86*
	Age-Sex nteraction	3	100.66	33.55	3	17.53	5.84	3	156.09	52.03
	Within Subclasses	43	775.39	18.03	41	1,719.78	41.95	42	1,206.99	28.74

nounced than during the First and Second Sessions; here as in the earlier sessions, there was less difference between the age groups in the simplest tests than in those using more stimuli. The differences between age groups were not consistent for the different tests in the smaller classifications of reagents into sex or I.Q. groups, nor were they in general as marked as in the total group of 100 reagents. When all reagents were considered together, the age groups covering consecutive ranges of slightly less than a year represented different levels of ability.

Sex differences in speed of reaction were not the same for the high as for the low I.Q. groups: in the former they were great, and in the latter insignificant, as appears in Table XV. Throughout all sessions, scores of the H boys represented definitely greater speed than did those of the H girls, whereas times of the L boys and the L girls were rather similar.

Interactions between the variables are not reliably different from zero.

The influence of I.Q. group was for both sexes and in all tests and sessions, significant, although for the girls somewhat less so in Tests I and IV of the First and Second Sessions than in other tests of those sessions or in any test of the Third Session. Throughout all sessions, not only were the H groups faster than the respective L groups, but both H groups surpassed either L group: the H boys were faster than any of the other groups, and the H girls, who in any test were definitely faster than the L girls, were, as is shown for the Third Session in Table XV slightly faster than the L boys in Test I, and in Tests II, III and IV were faster by an amount which can be termed significant.

CHAPTER V

SUMMARY AND CONCLUSIONS

In order to determine whether children of high differed from those of low I.Q. in speed and in variability of reaction and in relative decrease in speed accompanying increase in the number and the complexity of arrangement of potential stimuli, 51 children of Stanford-Binet I.Q. 120 to 200 were compared with 49 children of the same chronological age but of I.Q. 63 to 94 on the speed with which they could react to a visual stimulus by moving the hand a short distance before touching a response key.

Each of the five response keys, arranged in an arc whose radius was the distance from the finger-rest to the center of the button of any response key, was directly beneath one of the five one-watt Neon bulbs which served as stimuli. Only one light was used at any one time, and was presented after a signal. The apparatus permitted control of the preparatory period which was altered uniformly for all reagents over a range of from $\frac{1}{2}$ second to 5 or to 7 seconds; the clocks made a buzzing noise throughout the preparatory period and until the correct response was made. The response required the touching of the correct key as quickly as possible after appearance of the stimulus, using the finger which during the preparatory period had been on a finger-rest removed a little more than 2″ from any response key; the same finger and mode of response were used throughout. In order to minimize differences in technique and number of muscles involved in the response, a movable armrest was used.

A series of reactions was obtained to each of six tests: of the test situations in which response was to the key directly beneath the stimulus light, one involved only the center light and response key, another but two lights and keys, another but three, and one involved all five lights; more complicated were the two tests in which all five stimuli were used but in which any light was extinguished by another key than the one directly beneath it. Each series was preceded by a demonstration of the lights and response keys to be used. Premature reactions were mechanically prevented.

Each reagent was tested individually during three sessions of approximately 20 to 30 minutes during which the test was explained, practice given, and three or four series of reactions obtained. During the first and second test periods, 23 successive reactions were

obtained to each test; during these sessions the tests were presented in a different order to the reagents comprising each of four groups of the same average chronological age. During the third test period, 24 successful reactions were obtained to each of the four tests in which the correct response was to the key directly beneath the stimulus; during this session all reagents received the tests in the same order, only six good trials of any series being obtained successively. A good trial was one which the reagent considered valid; at the end of the group of six trials, a repetition was given of any trial in which he felt he had not been ready or in which he had missed the correct key.

Product-moment correlations were computed where suitable to the data. Comparisons of the experimental groups in regard to speed of response, and to decrease in speed accompanying increase in number of potential stimuli, were based upon time-unit differences between pairs of reagents of the same sex and within two months of the same chronological age, but in which one was a child of high and the other of low I.Q.: the significance of the mean differences between the pairs was evaluated by the application of "Student's" t-test for unique samples. In comparing the experimental groups on the variability around their own means of the individuals within the groups, t-values were based upon the standard deviation for each individual of his series of reaction times. Fisher's method for the analysis of variance was applied to the data to determine the relative influence on the results of such factors as I.Q. group, sex, chronological age, and the difference in order in which the tests were presented during the first two sessions.

Results obtained seem to justify the following conclusions in reference to the groups of boys and girls who served as reagents in the present experiment. As in any statistical study, there were on any of the bases of comparison individual cases out of line with the findings for the groups.

In a series of 24 reactions given in four groups of six reactions each, and in which premature responses were prevented, only moderate difference resulted when the mean instead of the median of all 24 trials was used as the reagent's score, or when trials the reagent considered invalid were discarded and the times of substitute trials used. (Table VII.)

When the reagents were permitted to decide that any trial was an invalid measure of their speed of reaction, in general they termed invalid fewer trials than the experimenter would have discarded

from watching the trial or on the basis of the deviation of the time from the times of the rest of the series of reactions. The experimental groups differed little in the average number of trials discarded. (Table II.)

Correlations of the tests repeated after several weeks and under different methods of procedure ranged from .67 to .77 when scores were plotted as deviations from the separate group means; split-half self-correlation of the tests given during the Third Session ranged from .85 to .89, or, after application of the Spearman-Brown formula, from .92 to .94. (Table III.) Reliability coefficients computed for the two I.Q. groups were greater for the L than for the H group in Tests II, III, and IV given in different sessions, and in Test III of the Third Session. (Table IV.)

The ranking of the individuals on the basis of speed was rather stable in the different tests given during the Third Session. (Table V.)

In speed of reaction the high I.Q. group of boys definitely surpassed the low I.Q. group in all the tests; the high I.Q. girls were faster than the low I.Q. girls, but differences between the groups were less marked in the simplest test than in those in which several potential stimuli were used. In the first two sessions the differences between the groups of girls on certain tests was less definite when the median time than when the mean time of their trials was used as the score. (Table VII.) In the two complicated tests *xa* and *xb,* both high I.Q. groups were definitely faster than the respective low I.Q. groups. (Table VII.)

There was practically no difference between the experimental groups in number of correct keys missed in either Test I or IV, involving response to the key directly beneath the stimulus; there was little difference between the groups in number of correct keys missed in the simpler of the two tests in which the correct key was not directly beneath the stimulus; but in the most complex test, the low I.Q. groups made more errors than did the high I.Q. groups. (Table VIII.)

The first time each test was given, in the two-, three- or five-light test the low I.Q. group of boys decreased in speed more than did the high I.Q. boys from their time in the one-light test; during the Third Session there was little difference between the groups of boys in relative decrease in speed accompanying increase in number of lights used. In all sessions the low I.Q. group of girls decreased more in speed from the one- to the two-light tests, but showed little

difference in decrease accompanying further increase in the number of lights used. With both boys and girls, in the complex tests *xa* and *xb* the low I.Q. group decreased in speed appreciably more than did the high I.Q. group from their speed in the simpler tests. (Tables IX.)

Members of the low I.Q. groups were significantly more variable in their response to any of the tests given in the Third Session than were individuals in the respective high I.Q. groups. Within either the low or the high I.Q. group there was little difference between the boys and the girls, except in the one- and the five-light tests in which the high I.Q. girls were less consistent than the boys. (Table X.)

In general, the order in which the various tests were presented had little influence on the time of reaction. (Table XII.)

Within the chronological age range of the reagents, speed differences between age groups were not consistent for the various tests in the smaller classifications of reagents into sex or I.Q. groups, nor were they in general as marked as in the total group of 100 reagents. When all reagents were considered together, the age groups covering consecutive ranges of slightly less than a year represented different levels of ability in speed of reaction. (Tables XII to XV.)

Scores of the group of high I.Q. boys represented definitely greater speed than did those of the high I.Q. girls, but in the low I.Q. groups times of the boys and girls were rather similar. The group of high I.Q. girls were in general faster than the group of low I.Q. boys. (Tables XV.)

Selection of the reagents on the basis of wide difference in I.Q. resulted in groups significantly different in speed and in consistency of response to the tests of the experiment reported here. Not only were the high I.Q. groups faster than the respective low I.Q. groups, but in general both high I.Q. groups surpassed in speed either low I.Q. group. (Tables XIII and XIV.)

Discussion

The results of the experiment reported here indicate that the question of the relationship between intelligence and speed of muscular response is still open. They point to the advisability of using children rather than adults in investigating the extent and type of activities in which a speed difference between the bright and dull exists, thereby avoiding the confusion of data which results from the combining of speed scores of individuals in different develop-

mental stages; to the advisability of using for the response a larger movement requiring greater organization than is involved in the more reflex-type of response customarily used in reaction-time studies, thus approximating somewhat more closely normal voluntary activity, and making possible more direct comparisons between the simple reaction and more complex types of discrete or of serial action; and to the advisability of using a group heterogeneous in I.Q. in attempting to determine whether speed ability is to any appreciable extent related to the types of ability measured by the Stanford-Binet intelligence test.

The extent of the implications for educational procedure of a genuine difference between children of high and those of low I.Q. in the speed with which they can make a muscular response to a visual stimulus probably depends upon not only verifying but broadening the conclusions of the present study, for discrete stimulus-response situations are not frequent. However, even the results of the present study indicate the possible fruitfulness of investigating the relative influence on learning by dull pupils of repetition as against mere change in the tempo of presentation of material and instructions. If further research verifies and broadens the findings presented in this report, thereby demonstrating a significant difference in speed of performance between individuals of high and those of low I.Q., there are implications not only for educational but also for vocational procedure: in general, the individuals of low I.Q. should not be expected to strike as many keys, change as many coins, press as many levers or cap as many jars as would brighter individuals in the same length of time; a slightly slower tempo might in itself alter situations in which the dull are confused and incompetent into situations in which they could achieve the satisfaction of success.

Further research on this problem of speed and ability might profitably be directed toward learning whether individuals of high and those of low I.Q. differ in speed and in the number of trials necessary before a certain criterion of accuracy is achieved in complex reaction series; in speed of performing serial tasks; in speed of response to sensory discrimination between simultaneously presented stimuli; in speed and accuracy on series in which logical discrimination between simultaneously presented stimuli is necessary; and toward determining how closely related are these aspects of the problem. The hypothesis is suggested as worthy of investigation that the relationship between I.Q. and reaction time is curvilinear.

APPENDIX

The following diagram was set up in an attempt to judge whether the relationship between I.Q. and reaction time seemed to be a linear one. The heavy lines join the mean times for the columns, each of which represents a 10-point I.Q. interval. The line for the higher I.Q. group does not seem to be a continuation of the line for the lower I.Q. group. This might be because the relationship is really a curvilinear one so that even in large groups the slope would not be the same at both ends of the distribution; on the other hand, it might be merely that the groups are so small that neither line is reliably determined.

In order that the data of the experiment reported here may be more readily available to anyone who might wish to repeat the experiment, perhaps including children representing the I.Q. groups not used in this experiment, summary data are given in Table XVI.[1]

[1] Arrangements for obtaining further data may be made with the author.

TABLE XVI. SUMMARY OF RAW DATA

Group	Reagent	I.Q.	C.A. at First Session	Order Group	First and Second Sessions (fastest 20 trials) Test I ΣX	Test I ΣX²	Test II ΣX	Test II ΣX²	Test III ΣX	Test III ΣX²	Test IV ΣX	Test IV ΣX²	Test xa ΣX	Test xb ΣX	C.A. at Third Session	Third Session (24 trials) Test I ΣX	Test I ΣX²	Test II ΣX	Test II ΣX²	Test III ΣX	Test III ΣX²	Test IV ΣX	Test IV ΣX²
HB	80	145	11-9	C	673	22,697	778	30,416	873	38,699	763	29,419	1078	2275	12-1	794	26,532	906	34,606	916	35,804	925	36,077
	38	146	11-8	D	632	20,142	625	19,890	613	19,036	593	17,949	1069	1981	12-0	729	22,299	791	26,271	848	30,246	817	28,255
	60	138	11-7	C	766	29,578	1079	59,333	1051	55,827	1001	50,802	1598	3361	11-11	828	28,684	927	36,081	993	42,267	999	42,225
	37	136	11-5	A	782	30,818	930	43,779	1068	59,164	1108	62,560	1541	3388	11-9	905	34,311	1084	49,372	1113	52,405	1206	62,386
	66	138	11-2	B	711	25,610	828	34,752	955	46,639	864	37,738	1239	2284	11-6	734	22,568	874	32,068	910	35,162	921	35,745
	36	146	11-0	A	649	21,194	748	28,222	724	26,459	810	33,639	1182	2436	11-4	811	27,611	964	39,066	1021	43,877	1030	44,742
	28	139	10-11	B	636	20,360	802	33,126	775	30,338	705	25,107	1186	2440	11-4	759	24,171	962	39,656	993	42,077	972	40,196
	84	194	10-9	C	649	21,155	837	35,295	879	39,227	797	31,985	1172	2174	11-1	769	24,799	924	36,056	998	42,032	1021	43,955
	54	140	10-6	D	765	29,825	900	41,482	880	39,416	972	48,682	1516	4021	10-10	875	32,155	1010	42,986	1074	48,854	1076	49,688
	35	120	10-6	B	714	26,024	874	38,501	941	44,785	748	28,663	1437	2389	10-10	911	34,953	1132	54,362	1303	72,701	1235	64,633
	85	142	10-5	A	690	23,951	830	34,700	872	38,506	858	36,920	1121	4118	10-9	729	22,229	878	32,292	963	39,311	982	40,692
	29	179	10-4	D	653	22,260	799	32,524	772	30,279	762	29,367	978	1904	10-8	823	28,339	956	38,774	1004	42,850	979	40,449
	49	150	10-3	B	748	28,431	855	37,094	813	33,410	736	27,448	1216	2136	10-8	804	27,116	986	40,848	979	40,317	1024	44,210
	12	144	10-2	B	704	24,969	804	32,577	866	37,935	770	29,721	1342	2507	10-6	787	25,921	881	32,669	973	40,403	1021	44,653
	113	163	10-1	B	859	37,223	1023	53,117	1127	64,967	953	46,135	2113	3116	10-1	886	33,128	1001	42,267	1064	47,968	1086	49,892
	47	122	10-0	D	718	26,090	921	43,051	834	35,233	873	38,635	1360	2741	10-4	920	35,504	1045	46,305	1091	50,701	1116	52,856
	7	158	9-10	A	695	24,493	775	30,361	819	34,508	800	32,308	1371	2744	10-2	731	22,437	827	29,197	891	34,485	852	31,116
	25	137	9-9	D	637	20,598	692	24,114	744	27,938	668	22,574	1695	4647	10-1	767	24,679	933	36,637	1013	43,405	1029	44,907
	77	150	9-8	C	665	22,493	947	45,545	867	38,209	832	35,681	1267	2511	10-0	750	23,550	836	29,534	866	32,004	815	27,953
	4	147	9-7	A	1005	51,239	1091	61,174	1037	53,961	993	49,774	1340	3460	10-0	1068	48,238	1229	65,181	1230	63,634	1248	65,566
	44	140	9-6	A	731	27,040	988	49,249	964	48,782	892	40,322	1430	3313	9-10	863	31,465	944	38,434	1040	46,318	1037	45,893
	78	142	9-4	D	882	39,135	995	50,545	983	49,193	991	50,345	1349	2194	9-8	885	33,129	962	39,024	1006	42,678	1024	44,658
	30	155	9-4	D	739	27,406	782	31,183	762	29,277	768	29,651	1434	2197	9-8	936	36,978	1054	46,608	1102	51,246	1080	49,142
	79	163	9-1	C	769	29,951	967	47,407	994	50,466	860	37,357	1341	2408	9-5	885	32,841	958	38,702	1052	46,912	981	40,545
	86	170	9-0	C	703	25,217	907	42,339	1026	54,086	828	34,504	1519	4056	9-3	761	24,295	929	36,419	1017	43,693	966	39,662
	9	140	8-11	B	710	25,449	873	38,981	931	44,520	777	30,738	1200	2568	9-3	864	31,332	941	37,619	927	36,295	923	35,791
Total*: N·26					18,885	703,348	22,650	1,018,757	23,170	1,070,860	21,722	938,024	35,094	73,369		21,574	759,264	24,934	1,021,034	26,387	1,147,645	26,365	1,145,887
N·25					18,154		21,662		22,206		20,830		33,664	70,056		20,688		23,933		25,323		25,279	

TABLE XVI (continued)

Group	Reagent	I.Q.	C.A. at First Session	Order Group	First and Second Sessions (fastest 20 trials) Test I ΣX	Test I ΣX²	Test II ΣX	Test II ΣX²	Test III ΣX	Test III ΣX²	Test IV ΣX	Test IV ΣX²	Test Xa ΣX	Test Xb ΣX	C.A. at Third Session	Third Session (24 trials) Test I ΣX	Test I ΣX²	Test II ΣX	Test II ΣX²	Test III ΣX	Test III ΣX²	Test IV ΣX	Test IV ΣX²
	76	153	11-5	C	893	40,125	1079	58,453	1085	59,215	1052	55,743	1467	2843	11-9	1020	44,046	1137	54,293	1187	59,171	1188	59,312
	67	120	11-4	B	741	27,609	804	32,531	949	45,419	938	44,540	1337	3162	11-8	850	30,224	949	37,831	1047	46,095	1018	43,838
	51	132	11-3	D	782	30,778	693	24,442	755	28,975	726	26,616	1384	2967	11-7	949	37,791	1023	44,059	1137	54,589	1073	48,671
	61	131	11-3	A	767	29,507	954	46,002	1084	59,992	1011	51,485	1342	2416	11-7	886	32,922	963	39,147	1011	43,299	1028	44,678
	27	134	10-9	B	733	27,059	842	35,663	983	48,461	937	44,019	1325	2284	11-2	1019	43,473	1051	46,619	1130	53,916	1121	53,451
	69	138	10-9	D	868	38,090	831	35,874	783	31,103	758	29,043	1289	2236	11-0	958	38,722	1032	44,680	1048	46,912	1045	46,233
	88	135	10-7	B	754	28,698	919	42,626	967	47,393	899	41,137	1465	3129	10-11	892	33,350	1102	51,492	1154	56,562	1152	56,382
	50	149	10-7	D	821	34,070	788	32,090	764	29,816	656	21,969	1564	3013	10-11	941	37,203	1047	45,981	1073	48,537	1059	47,479
	65	136	10-7	C	846	35,923	732	27,811	782	31,296	938	44,276	1253	2701	10-11	925	36,225	1022	44,120	1231	65,879	1226	65,094
	55	137	10-6	A	856	36,784	951	45,758	1137	65,559	1161	69,163	1595	3777	10-10	971	39,869	1102	51,422	1118	52,818	1076	49,042
	26	152	10-6	A	617	19,214	705	25,021	743	28,292	746	28,124	1093	2195	10-11	804	27,102	906	34,796	897	33,903	916	35,340
HG	64	124	10-6	C	712	25,543	1018	52,766	1042	55,248	995	49,975	1464	3460	10-10	767	24,847	965	39,981	1001	42,345	967	39,489
	24	130	10-4	A	769	29,708	891	40,249	912	42,026	880	38,886	1208	2398	10-9	975	39,875	1107	52,163	1175	58,257	1194	60,254
	46	138	10-2	C	779	30,630	745	28,293	747	28,629	846	35,890	1312	2876	10-6	827	28,635	888	32,976	946	38,232	918	35,776
	87	132	10-1	B	668	22,746	817	34,248	1022	53,666	923	43,359	1209	2763	10-5	770	24,962	900	34,578	988	41,716	953	38,571
	6	172	9-9	B	804	32,759	859	37,383	980	48,254	896	40,424	1317	3382	10-1	858	30,812	997	42,215	1038	45,578	1051	47,069
	43	149	9-6	D	810	33,082	981	49,143	992	50,772	997	50,997	1478	3303	9-11	924	35,996	995	42,031	1107	52,319	1079	49,849
	70	138	9-4	A	815	33,364	1064	57,151	1138	65,934	1159	67,883	1561	3482	9-8	988	40,926	1139	55,019	1322	73,380	1300	71,630
	57	140	9-3	D	832	34,956	1151	67,461	1132	65,252	1030	54,360	1646	3716	9-7	937	36,879	1108	51,920	1102	51,542	1176	58,398
	82	131	9-3	C	782	30,808	1026	53,254	1116	63,578	884	39,338	1916	3380	9-7	959	38,657	1023	44,119	1115	52,739	1108	51,822
	3	130	9-2	A	988	49,326	979	48,969	1080	58,849	910	41,519	1584	4434	9-7	1119	52,555	1224	63,216	1255	66,507	1261	67,881
	83	143	9-2	D	1038	54,722	905	41,778	1018	52,169	926	43,288	1934	3452	9-5	947	37,879	1108	51,816	1151	56,955	1174	58,654
	56	200	8-8	C	705	24,954	884	39,502	1035	56,095	992	49,651	1406	2653	9-0	780	25,720	938	37,370	1072	48,662	1073	48,899
	16	184	8-7	A	991	49,866	1009	51,613	1082	59,839	1038	54,731	1736	3383	8-11	933	36,545	1025	44,471	1091	50,849	1069	48,641
	14	140	8-6	B	862	37,447	1038	54,290	1210	73,731	1087	59,803	1605	2903	8-11	996	41,560	1120	52,776	1197	60,691	1158	56,470
Total:	N·25				20,233	837,768	22,665	1,062,371	24,538	1,249,563	23,385	1,126,219	36,490	76,308		22,995	896,775	25,871	1,139,091	27,593	1,301,453	27,383	1,282,923
	N·24				19,500		21,823		23,555		22,446		35,165	74,024		22,145		24,922		26,516		26,365	

TABLE XVI (continued)

Group	Reagent	IQ	C.A. at First Session	Order Group	First and Second Sessions (fastest 20 trials) Test I ΣX	Test I ΣX^2	Test II ΣX	Test II ΣX^2	Test III ΣX	Test III ΣX^2	Test IV ΣX	Test IV ΣX^2	Test xa ΣX	Test xb ΣX	Third Session (24 trials) C.A. at Third Session	Test I ΣX	Test I ΣX^2	Test II ΣX	Test II ΣX^2	Test III ΣX	Test III ΣX^2	Test IV ΣX	Test IV ΣX^2
	58	91	11-8	C	732	26,940	906	41,508	1039	54,811	897	40,957	1360	3232	12-0	834	29,144	948	37,880	1006	42,750	1019	43,747
	42	83	11-9	D	732	26,946	911	42,001	883	39,467	849	36,335	1252	3555	12-1	865	31,505	949	38,077	1024	44,684	1043	46,383
	75	80	11-7	C	822	34,076	1003	50,877	1041	54,843	924	42,927	1190	2557	11-11	931	36,265	1028	44,622	1046	45,990	1096	50,436
	45	83	11-5	A	726	26,577	883	39,478	1083	61,041	1232	78,918	1361	3673	11-9	945	37,369	1193	60,437	1239	65,115	1246	65,632
	111	63	11-4	B	929	44,043	1266	81,868	1135	65,485	1042	55,086	2665	3425	11-4	979	40,349	1176	59,164	1203	62,229	1205	62,499
	33	82	11-1	A	664	22,527	786	31,790	831	35,419	855	37,683	1382	3140	11-5	896	34,226	1008	44,614	1047	47,681	1017	44,329
	108	89	11-2	B	682	23,382	744	28,105	892	40,096	830	34,756	1389	2413	11-4	805	27,147	1000	42,666	1005	42,735	1040	45,438
	81	90	10-11	C	994	49,874	1195	73,763	1156	67,804	1186	70,647	1867	3766	11-3	936	36,986	1053	46,643	1133	54,343	1207	61,853
	32	91	10-11	B	723	26,262	946	45,163	877	39,117	828	34,688	1410	3857	11-4	855	30,729	973	40,501	1039	45,535	1074	49,734
	63	94	10-6	D	900	41,017	920	42,746	967	47,149	1035	53,821	1583	3939	10-10	1037	45,157	1161	56,849	1210	62,156	1189	59,807
	112	76	10-6	B	875	38,827	982	49,374	1314	92,774	977	50,017	2296	3023	10-7	889	33,203	1038	46,218	1231	65,837	1286	70,772
	23	87	10-6	B	927	43,619	957	46,234	881	39,172	823	34,158	1224	2222	10-10	1087	49,673	1176	58,820	1245	65,783	1231	65,121
LB	74	73	10-5	A	965	46,947	1095	61,372	1212	74,208	1125	64,793	2004	5185	10-9	1089	49,613	1241	65,007	1296	71,062	1311	73,273
	11	86	10-2	D	817	33,900	938	44,618	1151	66,758	1155	67,049	1877	4212	10-7	1012	43,242	1071	48,915	1111	52,915	1114	52,770
	109	67	10-1	A	693	24,599	866	38,388	821	34,313	847	36,281	2281	3078	10-2	859	30,809	989	41,027	1066	47,830	1002	42,192
	1	76	10-0	B	995	50,125	1149	66,933	1189	72,591	1125	64,161	2003	3629	10-1	1080	49,036	1223	62,643	1293	70,357	1258	66,652
	8	76	10-0	D	893	41,442	1254	80,292	1290	84,783	1307	86,628	1991	4709	10-5	1033	46,449	1257	67,727	1398	83,954	1459	92,373
	110	76	9-10	A	871	38,303	987	49,283	878	39,348	889	39,991	1652	3142	9-11	909	34,807	997	42,143	1043	45,837	983	40,781
	102	90	9-9	D	706	26,045	1049	57,951	1377	101,905	1306	89,788	1436	3812	10-0	863	31,349	1051	47,329	1143	55,701	1009	43,127
	72	81	9-7	C	840	35,858	989	50,207	940	45,042	890	40,192	2754	2327	9-11	774	25,256	841	29,745	933	36,899	881	32,529
	100	83	9-4	D	758	29,190	1037	57,505	1100	64,378	927	45,199	1843	3455	9-7	796	26,738	986	41,232	1161	57,681	1106	51,928
	101	89	9-4	D	824	34,762	1211	75,243	1180	70,694	1153	67,331	2432	4220	9-6	1040	45,920	1226	63,870	1258	66,766	1271	69,195
	107	71	9-3	C	1221	76,253	2326	276,054	1863	176,283	1884	181,617	4674	6047	9-6	1406	83,332	1583	105,627	1741	127,669	1775	134,113
	98	70	8-11	C	901	40,887	1200	73,068	1145	66,313	1166	68,377	1566	3242	9-1	964	39,120	1197	60,979	1337	75,687	1372	79,926
	20	83	8-9	B	1192	72,940	1487	114,474	1793	166,747	1677	144,483	3552	6873	9-1	1313	73,261	1540	100,232	1571	105,731	1536	101,016
Total: N-25					21,382	955,341	27,087	1,618,295	28,038	1,700,541	26,929	1,565,883	49,044	92,733		24,197	1,010,685	27,905	1,352,967	29,779	1,542,927	29,730	1,545,626

TABLE XVI (concluded)

Group	Reagent	I.Q.	C.A. at First Session	Order Group	First and Second Sessions (fastest 20 trials) Test I		Test II		Test III		Test IV		Test xa	Test xb	C.A. at Third Session	Third Session (24 trials) Test I		Test II		Test III		Test IV	
					ΣX	ΣX^2	ΣX	ΣX^2	ΣX	ΣX^2	ΣX	ΣX^2	ΣX	ΣX		ΣX	ΣX^2	ΣX	ΣX^2	ΣX	ΣX^2	ΣX	ΣX^2
LG	73	86	11-6	C	847	36,250	1160	67,986	1265	82,249	998	50,512	1681	3097	11-10	937	36,845	1019	43,731	1023	44,127	1030	44,622
	115	81	11-3	B	796	31,830	1003	51,335	1025	53,461	968	47,292	1684	1960	11-3	874	32,098	1022	44,194	1084	49,900	1070	48,578
	62	63	11-3	D	921	42,624	1214	74,140	1109	62,684	881	39,265	2953	4910	11-7	1104	51,118	1223	63,059	1353	77,285	1388	82,588
	59	85	11-2	A	977	47,899	1105	61,625	1109	62,021	1101	61,253	1556	3274	11-6	1037	45,049	1142	54,782	1180	58,708	1158	56,358
	52	82	10-9	D	777	30,467	861	37,959	922	43,421	919	43,628	2098	3508	11-1	986	41,328	1125	53,727	1169	57,909	1114	52,618
	99	72	10-8	B	928	43,792	1083	59,060	1031	53,733	1010	51,526	1604	6348	10-11	1005	42,367	1239	64,671	1237	64,695	1311	73,179
	39	90	10-7	D	864	37,624	908	42,151	916	42,247	857	37,103	1484	3358	10-11	1025	44,617	1165	58,425	1198	61,422	1206	62,576
	19	79	10-6	A	885	39,586	1242	78,072	1230	76,264	1216	74,569	1928	6428	10-10	1125	54,401	1292	69,924	1412	84,102	1427	88,407
	63	87	10-6	C	1026	54,816	1170	69,776	1168	68,954	1413	101,491	1799	3680	10-10	1130	54,112	1332	76,134	1366	78,926	1317	73,657
	41	89	10-5	C	804	32,567	1081	61,417	1022	52,772	965	47,074	1436	4628	10-9	990	41,708	1130	54,278	1137	54,683	1126	54,406
	68	84	10-5	A	867	37,936	1183	71,883	1024	52,876	1023	53,649	1580	3537	10-9	883	32,643	1034	45,078	1068	48,086	1026	44,536
	22	85	10-5	A	722	26,392	855	36,889	829	34,860	792	31,672	1572	2826	10-9	894	33,558	960	38,936	1010	43,214	1008	43,004
	106	77	10-2	C	833	36,026	1025	53,787	1170	69,078	1216	77,302	2293	5369	10-6	1031	45,055	1162	57,640	1279	69,509	1303	72,135
	89	85	10-1	B	961	47,502	1062	57,351	1207	73,605	1074	58,921	1716	3619	10-5	1066	48,094	1137	55,005	1169	58,107	1102	51,612
	21	85	9-8	B	703	24,943	818	33,763	975	48,110	807	33,103	1392	3009	10-0	842	29,636	989	41,121	1071	48,289	1099	51,025
	105	82	9-6	D	849	37,356	1053	56,531	1072	60,068	926	43,270	2252	4350	9-9	897	34,165	1039	46,173	1190	60,242	1175	59,571
	71	86	9-5	A	946	45,220	1027	53,720	1214	75,840	1233	76,849	1622	4166	9-9	1038	45,654	1253	67,111	1231	64,577	1268	68,472
	116	84	9-4	D	997	50,825	1134	66,194	1234	78,226	1183	71,977	2682	5119	9-5	908	34,760	1171	58,865	1268	69,130	1275	69,801
	10	84	9-4	C	770	29,892	1257	80,331	1298	87,226	1152	67,940	3295	4785	9-4	967	39,283	1287	70,487	1307	73,671	1407	85,321
	92	87	9-3	A	860	37,306	1041	55,515	1001	50,733	899	41,033	1806	3828	9-6	870	31,658	962	39,022	1068	49,118	1013	44,015
	34	75	9-2	D	1139	66,788	1824	183,595	1453	110,553	1983	214,722	3438	4854	9-6	1298	72,144	1506	96,718	1660	118,120	1562	105,688
	96	79	8-8	C	862	37,989	1269	83,983	1264	82,368	1002	50,737	1754	7666	8-11	1056	47,330	1238	65,082	1333	75,447	1333	75,999
	93	80	8-8	A	936	43,985	1180	70,196	1133	64,863	1146	66,150	1739	4022	8-11	1102	51,284	1187	59,097	1224	63,222	1210	61,496
	15	77	8-8	B	941	45,490	1081	60,283	1071	58,721	1034	54,028	3976	3662	9-0	969	39,357	1115	52,393	1288	70,638	1274	68,976
Total: N·24					21,211	965,105	26,636	1,567,542	26,742	1,544,933	25,798	1,495,066	49,340	102,003		24,034	1,028,264	27,729	1,375,653	29,325	1,543,127	29,202	1,538,640

†X = the time of one trial, expressed in hundredths of a second.

‡For the H groups, totals are given both for the entire group and for those members used in the comparisons of paired reagents.

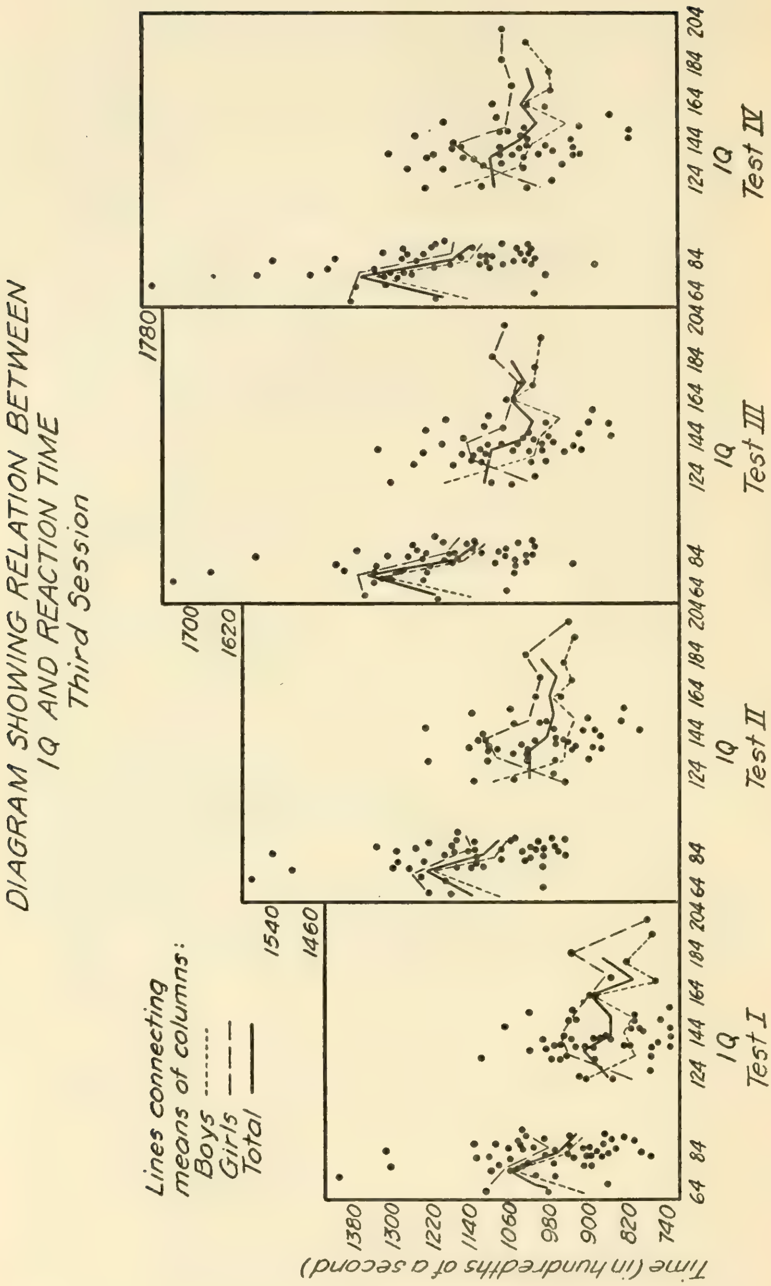
DIAGRAM SHOWING RELATION BETWEEN
IQ AND REACTION TIME
Third Session
Lines connecting
means of columns:
Boys
Girls
Total
Time (in hundredths of a second)
IQ
Test I
Test II
Test III
Test IV

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